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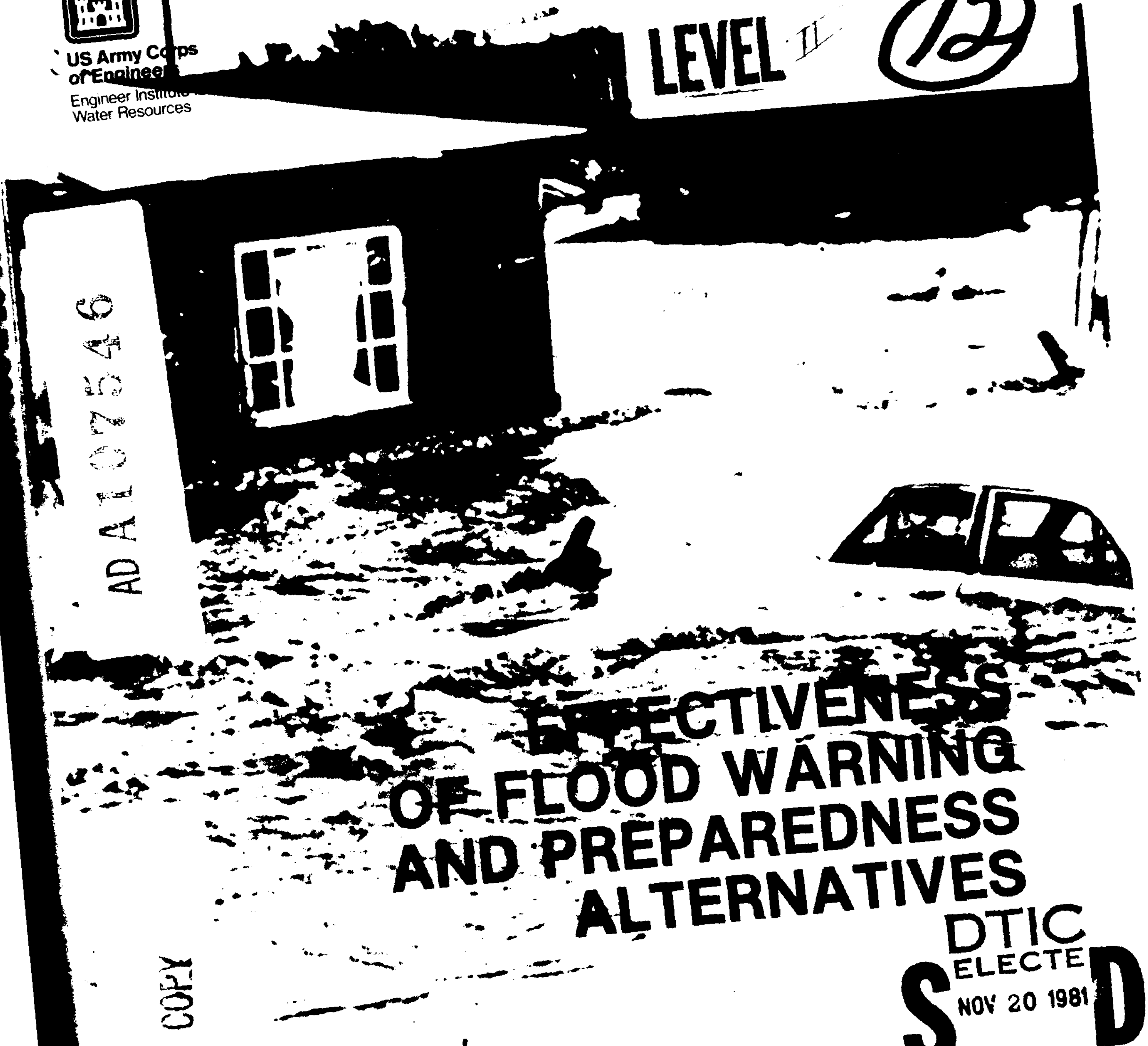

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The purpose of this report is to shed light on the question of the effectiveness of flood warning and preparedness alternatives and to suggest means of improving effectiveness. It is also intended as an aid to those considering the investigation and formulation of a community-level flood warning and preparedness alternative.

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EFFECTIVENESS OF FLOOD WARNING AND PREPAREDNESS ALTERNATIVES

CHAPTER 1

INTRODUCTION

Federal planners dealing with projects for flood loss reduction are required to consider nonstructural measures and, in some cases, to formulate nonstructural plans. These requirements are relatively recent and the state-of-the-art for planning, designing and evaluating most types of nonstructural measures is still rudimentary. The experimentation which has taken place to date in formulation and evaluation of nonstructural plans indicates the range of techniques available to the planner is not so large as was thought only a few years ago. It appears that only a few types of nonstructural measures will prove in practice to be physically and economically feasible for widespread use.

Community level flood warning and preparedness programs have emerged as one of the most promising nonstructural alternatives. They appear to be economically feasible in most situations for which they have been considered and the hardware and technology needed for their use is available. In addition, the concepts and procedures for plan formulation are relatively well developed. These indications of practicality are corroborated by the fact that several hundred community level flood warning and preparedness programs of one type or another are already established and operating in the United States.

The fundamental concept of flood warning and preparedness alternatives is that the adverse impacts of flooding can be reduced if information concerning an impending flood is made available on a timely basis and if plans and procedures for mitigating actions exist and are carried out. Alternatives which fully implement this concept can be designed to meet a variety of objectives. The broad objectives which they normally address are:

1. Reduction of injuries or deaths caused directly by floods;

2. Reduction of damage to movable property caused directly by floods;

3. Reduction of injuries, deaths and property damage caused by secondary problems related to flooding (e.g., fire, explosion, contamination of water supplies); and

4. Reduction of related costs not tied directly to property damages or losses from secondary problems.

Also, flood warning and preparedness alternatives or parts of such alternatives can and often do serve additional objectives. For example, in some local programs, the system for collection and analysis of hydrologic and hydraulic information is also used to assist in day-to-day operation of water control structures. The specific objectives to be served, along with the nature of the area to be protected and character of the flood threat, largely determine the activities to be included and the techniques to be employed in a particular flood warning and preparedness alternative.

Notwithstanding the considerable interest in flood warning and preparedness alternatives which have been generated by their apparent utility and economic feasibility, their consideration as recommendable parts of flood plain management for federal cost sharing has been inhibited by concern about their effectiveness. This concern stems from: a) the need for flood warning and preparedness alternatives to function under adverse meteorological and hydrological conditions; and b) the dependence for their success on appropriate responses to warnings by individuals, property owners and managers, and various public and private organizations.

PURPOSES AND INTENDED USES OF REPORT

The purposes of this report are to shed light on the question of the effectiveness of flood warning and preparedness alternatives and to suggest means of improving effectiveness.

Among other things, it provides guidelines for evaluating flood warning and preparedness arrangements which already exist for a particular locale. The need for consideration of a community-level warning and preparedness alternative is too often neglected or rejected by local officials on the basis of an unjustified assumption that it could provide no protection or benefits beyond that already available from the combination of the regular forecasting services of the National Weather Service and a community's existing general plan of emergency action. The report's discussion of effectiveness provides some suggestions of what to look for in judging the adequacy of existing arrangements.

The report is also intended as an aid to those considering the investigation, formulation and evaluation of a community level flood warning and preparedness alternative. Planners should find the material in the report useful in the preliminary evaluation of whether warning and preparedness is a viable concept for the case at hand, identification of the matters to be dealt with in investigation and plan formulation, and decision about the necessary level of detail of planning. In addition, planners should find the material useful in responding to the concerns and inquiries of non-federal interests about warning and preparedness alternatives.

SCOPE

Flood warning and preparedness alternatives are applicable to a variety of situations including riverine and coastal flooding, and to various causes of flooding including that from dam or levee failure and snowmelt as well as from heavy rains. However, interest in the use of warning and preparedness alternatives centers at present on riverine flooding. That is also the application for which the most progress has been made in development of design and evaluation concepts and for which the most information and examples are available.

The scope of the report is limited to the case of floods (flash and non-flash) in riverine situations which come with excessive rainfall. Other types of situations and other causes of flooding are not specifically addressed. However, much of what is presented in the report is applicable to other types of cases.

CHAPTER 2

ELEMENTS OF FLOOD WARNING AND PREPAREDNESS ALTERNATIVES

Flood warning and preparedness alternatives may be conveniently divided into four major elements, namely the:

1. Flood Recognition System;

2. Warning Arrangements;

3. Preparedness Plan; and

4. Maintenance Arrangements.

THE FLOOD RECOGNITION SYSTEM

The purpose of the flood recognition system portion of a warning and preparedness alternative is to determine if a flood is impending and predict the time of its occurrence and its magnitude. The flood recognition step is vital to a warning and preparedness program because it provides the basic information on which decision-making and action rests. Table 1 describes the principal approaches to flood recognition, and the types of systems usually employed. Brief descriptions are also included concerning the characteristics of each type of system.

Flood recognition systems which are limited to just the basic provisions for collecting and analyzing local precipitation and/or streamflow data are often inadequate. Unless the system includes at least some self-reporting gages, flash flood alarms, or provisions for continual monitoring, it may be possible for rains at night or in some remote part of the drainage area to go without official notice for a considerable period of time. The resulting late activation of the data collection system may cause a significant reduction in warning time.

Data collection systems which are operated continuously or which are activated promptly when rains begin may still be too limited since they only provide predictions based on rainfall or stream levels which

TABLE 1
FLOOD RECOGNITION SYSTEMS

Approach	Types of Systems	Comments
Measure Upstream Water Levels	Automatic Upstream Water Level Sensor System	Sensor sends signal to protected area when predetermined water level reached. Signal sent up to 15 miles on battery power or any distance by telephone. Vulnerable to disruption. Provides no information on rate of rise or ultimate height of flood waters. No analysis needed.
	Volunteer Operated Manual Crest-Stage System	Simple and inexpensive system. Potential for high accuracy. Lead time depends on travel time of waters from point of measurement to protected area. Observer's reports usually sent by telephone or radio. Analysis usually done by using charts and/or tables.
Measure Precipitation	Volunteer Operated Precipitation System	Simple and inexpensive system. Potential for somewhat less accuracy but longer lead time than with stream level measurement. Observer's reports usually sent by telephone or radio. Analysis usually done by using charts and or tables.
	Automated Precipitation System	Uses rainfall gages which can be interrogated by telephone or radio or which automatically signal increments of rainfall. Data transmission by radio subject to disruption. Automation provides 24—hour coverage and enables collecting data from locations where observers are not available.
Measure Stream Levels and Precipitation	Manual Combined Precipitation and Crest-Stage System	Offers best potential for providing both accuracy and longer warning times. May use either automatic gages, observers, or both.
	Computerized System	Provides 24—hour monitoring of conditions. Can analyze complex hydrologic situations with reservoirs, diversions, multiple sources of flooding, etc. Enables automatic linkage with NWS computers to use regional data. Enables examination of "what if" questions. Potential for high degree of accuracy. Generally most expensive type of system.

have already occurred. In small, steep basins subject to flash floods, travel times may be so short that warning times based on such information are inadequate. Also, of course, measurement of precipitation or stream levels gives no information about whether rains are likely to increase or how long they may continue. Persons planning protective steps which involve considerable time to execute may be caught in a dilemma with regards to initiating action.

These types of problems can be mitigated to a significant extent by supplementing local flood recognition systems with provisions for keeping abreast of weather conditions on a regional basis. The means usually employed include arrangements for provision of information from adjacent governmental units or for access to National Weather Service releases. Access to the NWS releases makes available longer range forecasts based on satellite imagery, synoptic data and radar. Access to NWS releases is usually through use of NOAA weather radios or subscription to a teletype service.

WARNING ARRANGEMENTS

The purpose of the warning arrangements portion of a flood warning and preparedness alternative is to assure flood predictions and necessary instructions are made available to affected parties. Table 2 summarizes the various categories of warning arrangements and the means of dissemination usually employed in each. Comments are also included describing pertinent characteristics of the various warning arrangements and means of warning dissemination.

Flood warning arrangements must provide for several basic activities including: a) determining whether the prediction developed through the flood recognition system warrants issuance of a warning; b) deciding the specific warning message to be issued; and c) delivery of the warning message to its intended recipients. The basic differences between warning systems with respect to how these activities are organized concern the assignment of responsibility for decision-making, whether or not the system is "staged", the degree of refinement of the warning procedures, and the means of disseminating warnings.

TABLE 2
WARNING ARRANGEMENTS

Category of Warning Arrangements	Means of Dissemination	Comments
Mass Warning System	Fixed siren and airhorn systems, commercial radio and television, mobile sirens, NOAA Weather Radio, mobile public address systems.	Warning intended to be equally available to all. Little or no selectivity in warning *only particular audiences or locations*. Usually passive since no action or investments is required to obtain warning (except for NOAA Weather Radio). Messages may not reach handicapped. New systems may be expensive. System may be prone to disruption due to loss of power. Widespread warnings may attract spectators.
Warning System for Special Recipient	Telephone, radio, messengers.	Warning intended only for specific parties, usually those responsible for mass warning or execution of preparedness plan. Features high degree of selectivity and ability to confirm warnings are received and understood. May also be used for parties with higher than normal risk or problems in responding such as hospitals, convalescent homes, jails, schools, etc.
Site-Specific Warning System	Public address systems, bells, sirens, horns, fire alarms.	Required for some facilities or locations including: a) where mass warning systems cannot be heard; b) hotels, motels and other locations where strangers to area may need special instructions; and c) where mass warning systems are not available such as parks or campgrounds.

Responsibility for Decision-Making

Flood warning and preparedness alternatives usually provide for at least a part of the decision-making regarding issuance of warnings to be closely allied with coordination and operation of the data collection network and preparation of flood predictions. If information and data collected through a local flood recognition system are provided to the National Weather Service for analysis and preparation of the flood prediction, that agency is normally depended on for the origination of warnings. In that event, warnings are usually released over television and radio at the discretion of the NWS and given directly by that agency to some local official by telephone, telegraph, radio or another available means. Local officials must then complete the decision-making process by deciding whether or not to mount any further warning dissemination effort.

If the analysis of data and preparation of the flood prediction is performed locally, decisions about warning dissemination are usually made entirely by local officials. In this case, the major variation in assignment of responsibility concerns whether the decision to issue and disseminate warnings is made by one person or through a chain of command. Each approach has advantages and drawbacks. The review provided by moving decisions through a chain of command serves to reduce errors and hasty judgments. However, it may seriously affect the timeliness with which warnings are finally made available.

Staging of Warnings

It is important that flood warnings issued to the public are timely and accurate. Warnings which are received too late are of little or no value. Warnings which are significantly in error may cause unwarranted complacency or result in expensive and troublesome overreaction. Shortcomings of either type erode the credibility of future warnings.

Warnings can generally be made more accurate by postponing their release until flooding is imminent and the magnitude and timing of the *impending* flows are obvious. But that defeats the objective of giving timely notice. The need for timeliness suggests that warnings be issued early in a potential flood episode, even if only incomplete data and information are available. The two criteria conflict except in unusual circumstances.

The need for timeliness frequently varies throughout the area served by a warning and preparedness alternative. Upstream portions of an area may need warnings considerably in advance of those further downstream. And the occupants of the lowest-lying flood plains usually need warnings earlier in a flood episode than those at higher elevations. Other variations may occur depending on whether the area is rural or urban, residential or commercial, or whether topography and other factors make movement to safety an easy or difficult task.

The need for timeliness also depends on the nature of certain activities, the degree of risk presented by a flood, and the *length of time required to take* preparedness actions. Public officials, emergency services agencies, hospitals, schools, jails, certain industries, invalids and others may need far longer warning times than the general population to take whatever action is expected of them in a flood emergency.

The accuracy required to make a flood warning valuable also differs with respect to party, location, activity, and other factors. For example, determination that overbank flows will occur may be adequate for some very low-lying areas even in the absence of any accurate information as to the eventual maximum height of the flood crest. Occupants of higher areas may be reluctant to take action unless it is relatively certain that the flood will affect their property. Also, for example, public officials and private property managers may have available some preparedness actions which do not involve significant expense and which can therefore be taken on the basis of preliminary warnings while undertaking the commitments involved in other actions may require more certain knowledge that flooding will occur.

All of these diverse needs for timeliness and accuracy cannot often be satisfied by issuance of a single "flood--no flood" announcement. Reconciliation of the several needs is usually accomplished through staging of the warning arrangements. Staging provides for identification of several "levels", "stages", or "conditions" of flood, usually based on combinations of the certainty of the flood occurring and the magnitude of the anticipated flows. A simply staged warning plan may provide as few as three stages corresponding to normal (no flood expected), pre-emergency (potential flooding), and emergency (flooding certain or underway) situations. Other systems may provide a half-dozen or more stages developed differently for each of several sub-areas.

No single pattern of staging is universally applicable for flood warning arrangements. What is appropriate in a particular case depends on local preference as well as topographic, hydrologic, developmental and other considerations. The staging must also mesh with the arrangements for warning dissemination and the preparedness plan.

Degree of Refinement of Warning Procedures

Warning arrangements may be very basic in some situations. For example, it might only be necessary in the case of a small community for a police or fire dispatcher to turn on a community siren when an upstream water level sensor indicates a flood is imminent. But even then, prudence suggests that there be some established procedure or standing order so experienced staff are reminded and new personnel are made aware of the action to be taken and instructed in its accomplishment. In most areas, the warning arrangements are far more complex and involve a number of people and organizations which must act in harmony if warnings are to be properly distributed to their intended recipients. The procedures to guide their coordinated actions must be correspondingly more detailed.

The actions which must be taken to carry out a warning process are dictated by what is to be accomplished. The options available to the planner in preparing the necessary procedures concern the detail and fullness of the instructions for these actions.

Procedures for even complex warning plans may vary with respect to their detail. Objective oriented procedures may only identify what overall actions are to be accomplished and leave the manner of accomplishment to the discretion and innovation of the responsible party. For example, procedures might only instruct the person responsible for issuing warnings to "review flood predictions and issue warnings as appropriate". A more detailed procedure might provide a basis for review through the use of decision criteria couched in terms of predicted flood magnitude. Additional detail could be added to procedures by including lists of persons and their alternates to be issued warnings, provision of telephone numbers and addresses, and wording of the warning message(s) to be used. These same sorts of refinements can be included or not included in other portions of the procedures to vary their level of detail.

Procedures can also be made fuller and potentially more valuable through inclusion of information which may prove useful to deal with contingencies. This may include names and telephone numbers of staff in federal and state disaster offices, listings of private contractors with potentially useful equipment, maps and plans, and mutual aid agreements.

The function of written procedures is to insure no serious errors or omissions are made. In deciding their appropriate level of detail and fullness, it must be borne in mind that the warning arrangements are likely to be executed under stressful and hurried conditions.

PREPAREDNESS PLAN

The preparedness plan is an important part of any alternative since it normally provides a large share of the benefits which justify expenditures on the flood recognition system and warning arrangements. As noted in Chapter 1, the objectives to which flood preparedness plans are most often addressed include safety from primary and secondary risks related to flooding, reduction of damages from primary and secondary risks, and reduction of costs other than those resulting from direct flood damages. Table 3 describes the major components of preparedness plans and the types of actions making up each component.

TABLE 3
PREPAREDNESS PLANS

Plan Components	Activities Making up Component
Evacuation and Rescue	Identify areas requiring evacuation. Provide transportation assistance. Disperse fire and police personnel and equipment to provide emergency services in threatened areas. Provide shelter and care for evacuees.
Damage Reduction	Curtail electric and gas service. Temporary floodproofing of structures and facilities. Flood fighting. Temporary relocation of movable property.
Traffic Control and Security	Mark evacuation routes. Expedite evacuation traffic. Expedite movement of emergency vehicles. Prevent unauthorized entry into evacuated area. Prevent unknowing travel into flooded areas.
Maintenance of Vital Services	Placement of equipment and personnel to maintain fire, police, medical and other essential services for all areas. Temporary floodproofing of vital facilities. Provision of auxiliary power, heat, water and other services. Identification of alternate routes for access to areas. Protection of vital documents and records.
Recovery	Maintenance of public health. Return of utility and other public services to operation. Rehabilitation and repair. Mobilization of assistance. Damage assessments. Provision of temporary housing. Debris disposal.

Role of Government in Plan Execution

Some parts of a flood preparedness plan require governmental participation for proper execution. For example, private citizens and private organizations cannot ordinarily disperse emergency equipment, provide effective traffic control, or modify the normal operation of utility systems. However, individuals and private organizations can be left wholly responsible for their own evacuation, temporary relocation of their movable property, care and shelter of evacuees, and contingency floodproofing of private homes and other facilities.

Some of the activities which could be left for private sector performance can be done better by government or with governmental assistance. For example, evacuation might be more completely and more rapidly accomplished if busses from the local transit system were made available. While care of evacuees could perhaps be provided by individuals, churches, and service organizations, it might be simplified if the kitchens, showers and other facilities of schools were used. And even though individuals could perhaps move a significant amount of their property out of a flood's path, local government's provision of a secured storage area could be important to the success of such an effort.

Opportunities for more or less governmental involvement exist for many aspects of preparedness plans. Selection of the appropriate level of governmental participation constitutes a major policy decision in plan formulation. The decision must, of course, be tempered by the amounts and types of personnel and physical resources available to local governments and the priority assigned to the plan's various objectives.

Format of Plans

The numerous activities of various parties which go into making up a preparedness plan lend themselves to presentation in a variety of formats. The three most popular formats are organization of the material by: a) agency or organization; b) stage of emergency or predicted flood level; and c) subplans for groups of related activities. None of the potential ways of organizing the plan is particularly superior to others and the choice is largely one of what works best for the case at hand. The more important point is that the plan must set forth in unmistakably clear language what is to be done, when or under what conditions each action is to be taken, and who is responsible for its accomplishment.

Preparedness plans are action documents intended for use under emergency conditions. This suggests that the plan be stripped of nonessential information, indexed and otherwise put together in a way which facilitates its convenient use. It should also be recognized in selecting a format for the plan that the intended participants in execution of the plan have differing needs for guidance. While a civil defense director responsible for orchestrating the community-wide response to a flood has need for the whole plan, the water plant supervisor may need only the instructions pertinent to operation of that utility. Some formats of plan presentation are better adapted than others to meeting these varying needs for information.

MAINTENANCE ARRANGEMENTS

The objectives, procedures, equipment, agreements and other things composing a flood warning and preparedness alternative require periodic attention if the effectiveness of the overall alternative is to be preserved. The function of the maintenance arrangements portion of a flood warning and preparedness alternative is to provide that necessary attention. The activities making up the maintenance arrangements can be subdivided into those for updating, testing, and education and information.

Updating

Updating is primarily a planning activity aimed at identifying and making modifications in the plan which are needed because of particular events which have taken place or because of the accumulation of minor changes which have occurred over time.

The portions of plans most likely to require updating are the minor items such as names and telephone numbers and those items of an expressly limited life such as contracts or memoranda of understanding. However, other needs for updating may also arise which are more complex and which require that some extent of replanning be done. For example, changes in land use in the watershed above a protected area or installation of upstream water control structures may change the timing or extent of the flood risk. Likewise, community growth or new development in the protected area may modify the flood hazard. Even changes in public attitude may result in a need to modify plans so as to make them serve some additional or other objective.

The appropriate frequency of updating depends upon the importance of the portion of the plan being considered, the penalty of relying on outdated information of various types and the resources required for updating.

Testing

Testing refers primarily to equipment, supplies, and other material items. Examples of testing activities include checking inventories of emergency supplies, testing gages and communication links, periodic trial of sirens and occasional operation of auxiliary generators.

The desirable frequency of testing depends on how often an item is used during the regular course of activities, its vulnerability to failure, the item's importance to the success of the alternative, and the resources required for testing.

Education and Information

Most preparedness plans depend to some extent on a knowledgeable public. At a minimum, the public may be expected to know that some preparedness plan and warning system exists and to recognize a particular signal. They may also be expected to know evacuation routes, the location of safe refuges and other information. Local officials and designated participants in the operation of the alternative are usually expected to have detailed knowledge about some parts of the alternative and the skills necessary to carry out their role.

Assuming that people have the knowledge and skills would be imprudent unless there is an education and information program. Several types of activities may be necessary including programs for general public awareness, training sessions for officials, and practice sessions.

CHAPTER 3

CRITERIA FOR EFFECTIVENESS

The principal criteria for judging the effectiveness of flood warning and preparedness alternatives are:

Comprehensiveness;

Realism;

Reliability;

Accuracy; and

Timeliness.

Table 4 lists the aspects important to each of the criteria and items to be considered in evaluating each aspect.

APPROACHES TO IMPROVING RELIABILITY

Reliability is one of the more difficult criteria to meet. However, the planner has five general approaches available for promoting reliability including: a) redundancy; b) separation of systems; c) fail-safe design; d) detailed design; and e) checking and confirmation.

Redundancy

Redundancy relies on having enough back-up provisions for critical parts of the flood warning and preparedness alternative that the probability of their simultaneous failure is limited to an acceptably low level. Examples of redundancy include:

1. Use of more than the minimally required number of precipitation and stream level observers and/or observation sites to guard against unavailability of data due to vacation, sickness or other factors related to observers or malfunction of an automatic gage;

TABLE 4
CRITERIA FOR EFFECTIVENESS

Criteria	Aspects	Items to be Considered
Accuracy	Types of data	Potential for predictions based on stream flow measurements to be more accurate than those based on precipitation measurements, value of combined systems, impact on cost and warning time of approach taken to data collection.
	Quantity of data	Time increments of data sets, comprehensiveness and density of data collection network, frequency of data collection, representativeness of drainage area.
	Quality of data	Type of data collected, type of device used for measurement, adequacy of measurement locations, provision for night observations, access to gages during flooding, availability of control sections for stream gages.
	Analytical procedures	Seasonal effects on runoff, variability over drainage area of soils and slope, effect of reservoirs, accuracy of technique to extrapolate rainfall data, ability to improve forecasts with experience and additional data.
	Errors	Observation, reporting, recording, garbled transmissions, false data due to malfunction, need for data screening programs, potential for errors in performing analysis, means of checking and verification.
Timeliness	Flood recognition system	Type of flood recognition system, travel time between point of measurement and protected area, speed of communications, time required to activate data collection network, time required for analysis.
	Flood warning arrangements	Time to determine affected area, decide on appropriate action, formulate warning message, and deliver messages.

TABLE 4
CRITERIA FOR EFFECTIVENESS (Cont'd)

Criteria	Aspects	Items to be Considered
Comprehensiveness	Sources of flooding	Rivers, smaller tributaries, sheet flow, streams with partial protection from structural works.
	Thoroughness of warning	Need to reach all affected parties including occupants and managers of property, emergency services agencies, utility managers, and parties responsible for warning dissemination and conduct of response action.
	Types of risk	Direct and indirect threats to safety from flood waters and/or damaged facilities and structures, protection of buildings and equipment from direct loss, risks associated with evacuation, loss of vital records, secondary losses.
Realism	Conditions for warning	Weather conditions, availability of personnel and equipment, flooding of underpasses, disruption of telephone and power service, downed trees, high ambient noise level, availability of mutual aid assistance, other storm—related duties for emergency services personnel.
	Reconciliation of resources	Availability of adequate people and equipment. Need for proper skills. Need for legal authority to perform planned functions. Other emergency uses of needed equipment. Time sequence of planned activities and needs. Potential for substituting equipment for personnel to relieve shortages.
Reliability	Availability of key personnel	Data collection observers, data collection system coordinator, flood forecaster, parties responsible for warning dissemination, persons with legal authority to direct evacuation and other response actions.
	Activation of data collection system	Determining when to activate system, means of communicating with observers, need for mobile radio—equipped observers.
	Detection of all floods	Density of data collection network, frequency of reporting, coverage of all sources of flooding, 24—hour operation.
	Dependability of equipment systems	Automatic gages, communications equipment, power system, telephone system, computers and peripheral equipment, access to data for manual processing, trigger circuits for mass warning equipment.
	Performance of participants	Assignment of responsibility to existing organizations, need for binding arrangements through contracts and memoranda of understanding, need for formal adoption of plan, making portions of plan into law to make compliance mandatory. Availability of necessary capabilities.

2. Appointment and training of one or more alternates for each position essential to operation of the flood warning and preparedness alternative which requires special knowledge, skills or legal designation;

3. Stockpiling of spare equipment and supplies required for essential activities;

4. Provision of auxiliary power sources; and

5. Provision of multiple means of carrying out particular functions such as communications among participants and dissemination of warnings.

The foregoing are only illustrations and not by any means the sole applications of redundency. Many other aspects of flood warning and preparedness alternatives are suited to use of redundancy to promote reliability.

The need to incorporate redundancy in flood warning and preparedness alternatives and the appropriate extent of redundancy depends on the vulnerability to failure of the alternative's main components and their importance to achieving the objectives of the alternative. Critical parts of the alternative warrant first attention with respect to provision of back-up arrangements. Several levels of back-up may be required if the back-up systems also are relatively vulnerable to failure.

Separation of Systems

The objective of system separation is to ensure that a failure of some particular type such as disruption of telephone service, loss of an antenna, malfunction of a computer or loss of electrical power does not cause total failure of the flood warning and preparedness alternative or any of its critical parts. The concept of separating systems is particularly cogent with respect to the use of redundant systems for such things as the means of collecting data, transmitting information, and making the flood prediction. For example, if back-up systems for some function operate from the same power source as the primary system for the function, a single failure in the power supply could render both the primary and secondary systems useless. Examples of system separation include use of gages with battery power telemetry capability to back-up gages interrogated by telephone and availability of manual forecasting procedures to back up computerized systems.

Fail-Safe Design

The period between floods may be long and there may be a significant risk that data collection equipment will fall into disrepair and that memories of operating procedures and analytical techniques will dim. This degeneration of the flood warning and preparedness alternative may happen without notice and be discovered only when an emergency occurs that requires use of the equipment and procedures.

These sorts of problems can and should be eliminated through conscientious conduct of a comprehensive maintenance program. However, concepts of fail-safe design also provide two ways to deal with them. First, equipment packages can often be designed to be self-monitoring and to provide notice of any internal malfunction. This type of fail-safe design is particularly relevant to Flash Flood Alarms and other eletromechanical equipment. A second approach to fail-safe design hinges on reversing the normal concept of the flood recognition system and viewing it as a means of assuring that a flood is <u>not</u> imminent. Any malfunction or out-of-the-ordinary event is then treated as if it signalled an impending flood. The result of this approach is a need for continuous operation of at least a part of the flood recognition system. Fail-safe design of this type is particularly relevant to procedures for bringing the flood recognition system to fully active status and for early alerting of local officials and emergency services agencies.

Detailed Design

Many parts of a comprehensive flood warning and preparedness alternative cannot be tested or practiced under the actual conditions expected to prevail at the time they are needed. This opens performance to a variety of problems stemming from inadequately detailed analysis and design.

Proper formulation of a warning and preparedness alternative requires a good knowledge of the area at risk with respect to its important characteristics. For example, it makes a difference in formulation of the arrangements for warning dissemination if the area at risk includes an enclave of persons who do not own radio or television sets for religious or other reasons. Or, for instance, what goes into effective arrangements for evacuation may differ radically between suburban areas where most families have at least one vehicle and central cities where ownership of a private vehicle may be the exception. As a further example, resort areas with high daily populations of transients pose quite a different problem of giving instructions about reaching areas of safety than do communities made up of permanent residents who can be reached more easily through continuing education programs and who can better comprehend descriptions of routes and destinations.

It is also essential for the planner to have a detailed understanding of the potential causes and types of flooding against which the flood warning and preparedness alternative is to provide protection. Flood recognition systems designed to identify only flooding of the slowly occurring type caused by sustained rainfall can differ significantly from systems aimed at identifying flash floods caused by small intense thunderstorms. Similarly, the potential rate of rise and ultimate height of flood waters affects the time which may be available for warning dissemination and response and the area to be included in a response plan. Whether or not flood flows will contain debris, their velocity and other characteristics may all be valuable clues as to how the warning and preparedness alternative should be formulated.

These various types of opportunities for error due to lack of knowledge about the situation continue throughout the formulation and design of both technical and other aspects of flood warning and preparedness alternatives. The cure for these sorts of problems is analysis and design at a level of detail commensurate with the intended importance and effectiveness of the product.

Checking and Confirmation

Flood warning and preparedness alternatives must often be executed on short notice, at late night hours, and under rushed conditions. These sorts of adverse conditions encourage mistakes and poor judgment. Even simple errors such as transposition of numbers in a piece of data may have serious repercussions. And despite other safeguards, equipment may give erroneous reports as, for example, an automatic gage that sends a false signal due to a lightning strike in its vicinity.

Sending a warning message over the airwaves does not assure that it will be received. Neither does successful delivery of a message assure its import is recognized and its purpose comprehended. And issuance of a directive does not necessarily mean the specified actions are carried out properly or even at all. Many such opportunities exist for incomplete performance.

To guard against these types of problems, the planner can build checks and confirmation procedures into the flood warning and preparedness alternative. Among others, these might include comparison of flow predictions made on the basis of rainfall with those based on upstream water levels, use of chains of command to review decisions, separate analysis and interpretation of basic data to verify predictions, and callback procedures to confirm receipt of warnings and performance of tasks.

COST-EFFECTIVENESS

The overall purpose of flood warning and preparedness programs is to reduce the impact of flooding. As noted in Chapter 1, the principal ways of accomplishing that purpose are by improving safety, reducing losses from property damage, and/or reducing economic losses other than property damage. Tables 5, 6, and 7 list some of the ways in which flood warning and preparedness programs may contribute to safety and loss reduction. The extent to which programs can provide the types of benefits cited in Tables 5 through 7 depends largely on the length of warning time that is made available and the nature of response actions which are preplanned.

TABLE 5
POTENTIAL BENEFITS OF FLOOD WARNING AND
PREPAREDNESS PROGRAMS
FOR
SAFETY

- Evacuation of hazardous areas prior to flooding, thereby reducing risks to both evacuees and rescuers;
- Provision of early alerts and any needed assistance to individuals who are invalid or handicapped, and other persons or organizations which require more than the normal amount of time to evacuate;
- Provision of a basis for deciding the opening and closing of schools, transportation of students, and release of employees from work so as to minimize exposure to danger;
- Timely institution of appropriate traffic controls to prevent travel into hazardous areas and facilitate evacuation;
- Deployment of personnel and equipment to assure medical, fire, police, and other services are continued and available to all parts of the community;
- Emergency management of gas and electric services and other actions to avoid fire, explosion and other secondary problems; and
- Minimization of public health problems in the post-flood period.

Not all of the types of potential benefits listed in Tables 5 through 7 are appropriate for consideration in evaluating the economic justification for a proposed flood warning and preparedness program. Benefits relating to life-saving and such things as reduction of hardship or anxiety must usually be considered under the environmental or social well being accounts rather than as a contribution to national economic development. However, the list of benefits which do have a determinable economic value and should be explicitly considered is still lengthy.

TABLE 6

POTENTIAL BENEFITS OF FLOOD WARNING AND PREPAREDNESS PROGRAMS FOR REDUCTION OF PROPERTY DAMAGE

* Movement out of the flood plain or to a safe elevation of automobiles and other mobile equipment, furniture, valuable papers and documents, business stocks, harvested crops, livestock and other property;

* Protection in place of fixed equipment by disconnection of electrical service, greasing, wrapping and other techniques;

* Protection of structures by sandbagging, anchoring, implementation of semi-permanent floodproofing measures, intentional flooding of basements and other means.

Some of the benefits appropriate for consideration are poorly defined because they have not been given much attention in the past. The types of potential benefits listed in Table 7 are examples of these. Nevertheless, the sorts of benefits cited in Table 7 are real and do occur. In fact, in the interviews on which the case studies in Appendix A are based, local officials cited various items in Table 7 as the major benefit derived from their flood warning program. It is important therefore that evaluation not overlook them.

The technique for evaluating the benefits attributable to reductions in flood losses are relatively well defined in the case of real property. The usual procedure is to construct stage-damage curves for various categories of property and to sum up damages prevented for various levels of protection. The same general approach is applicable to evaluation of the flood damages to property which are prevented by warning and preparedness programs except that the concept of a specific level of protection is largely irrelevant. Instead, the lead time of warnings and the degree of response to warnings furnish the variable on which the extent of damage reduction depends for a given level of flooding.

TABLE 7
POTENTIAL BENEFITS OF FLOOD WARNING AND PREPAREDNESS PROGRAMS
FOR
REDUCTION OF LOSSES OTHER THAN PROPERTY DAMAGE

* Orderly shutdown of production facilitites or modifications in procedures to continue production;

* Faster and less expensive return to normality, resulting in reduced unemployment, smaller losses in sales, and less reduction in sales taxes collected;

* Prevention of undue reductions in property value and consequent reductions in tax revenues;

* Reduced costs due to fire, explosion, contamination of water supplies, sewage spills and other secondary problems;

* Reduced needs for overtime of employees for flood fighting, rehabilitation and other purposes;

* Elimination of costs for precautionary actions found later to have been unnecessary;

* Reduced costs for emergency shelter, care and public assistance for evacuees;

* Reduced risk of liability for injury to or death of patrons, students, patients, visitors and employees of public and private facilities; and

* Reduced costs for flood insurance through reduction in amounts of coverage required.

A computational technique for estimating the property damage reduction component of benefit attributable to flood warnings has been described by Day and

Lee.[1] Figure 1 illustrates the procedure in schematic form. As shown in the figure, the key inputs of information and data are flood plain hydrology, an inventory of property, and stage-damage tables for buildings on the flood plain. The stage-damage tables referred to in the figure are for conditions of no warning (NW), limited warning time (LWT) of 6 to 12 hours, and maximum practical evacuation (MPE) corresponding to a warning time of 12 to 24 hours. The "no warning" condition is intended to represent the maximum loss that can be incurred and the "maximum practical evacuation" case is that in which all movable items are evacuated. The accuracy of the overall procedure is described by the authors as being ± 25 percent.

The procedure outlined by Day and Lee has several advantages. It is relatively straightforward in concept and parallels the analytical approach used for evaluating benefits of several other types of measures. It also lends itself to computerization to handle the large amounts of data encountered where many categories of structures are involved. However, the procedure also has a major shortcoming in the arbitrariness involved in establishment of the stage-damage curves.

It is clear that the stage-damage curves reflecting various lengths of warning time fall between one representing "no warning" and one representing "maximum probable evacuation". But estimates of damage under each of these conditions also depends on the proportion of property managers which receive and act on warnings. A family of stage-damage curves is necessary to encompass variations of both length of warning time and degree of response.

Moreover, the shape of the stage-damage curve can be expected to vary according to the degree of preparedness on the part of property managers. Property managers who assess the potential for flood damage and develop a plan to make the most cost-effective use of warning time can achieve greater savings than those who do not. This type of variation is especially to be expected in the case of shorter warning times.

[1] Day, Harold J., and Kwang K. Lee. "Flood Damage Reduction Potential of River Forecast." Journal of the Water Resources Planning and Management Division. ASCE. April 1976. pp. 77-87.

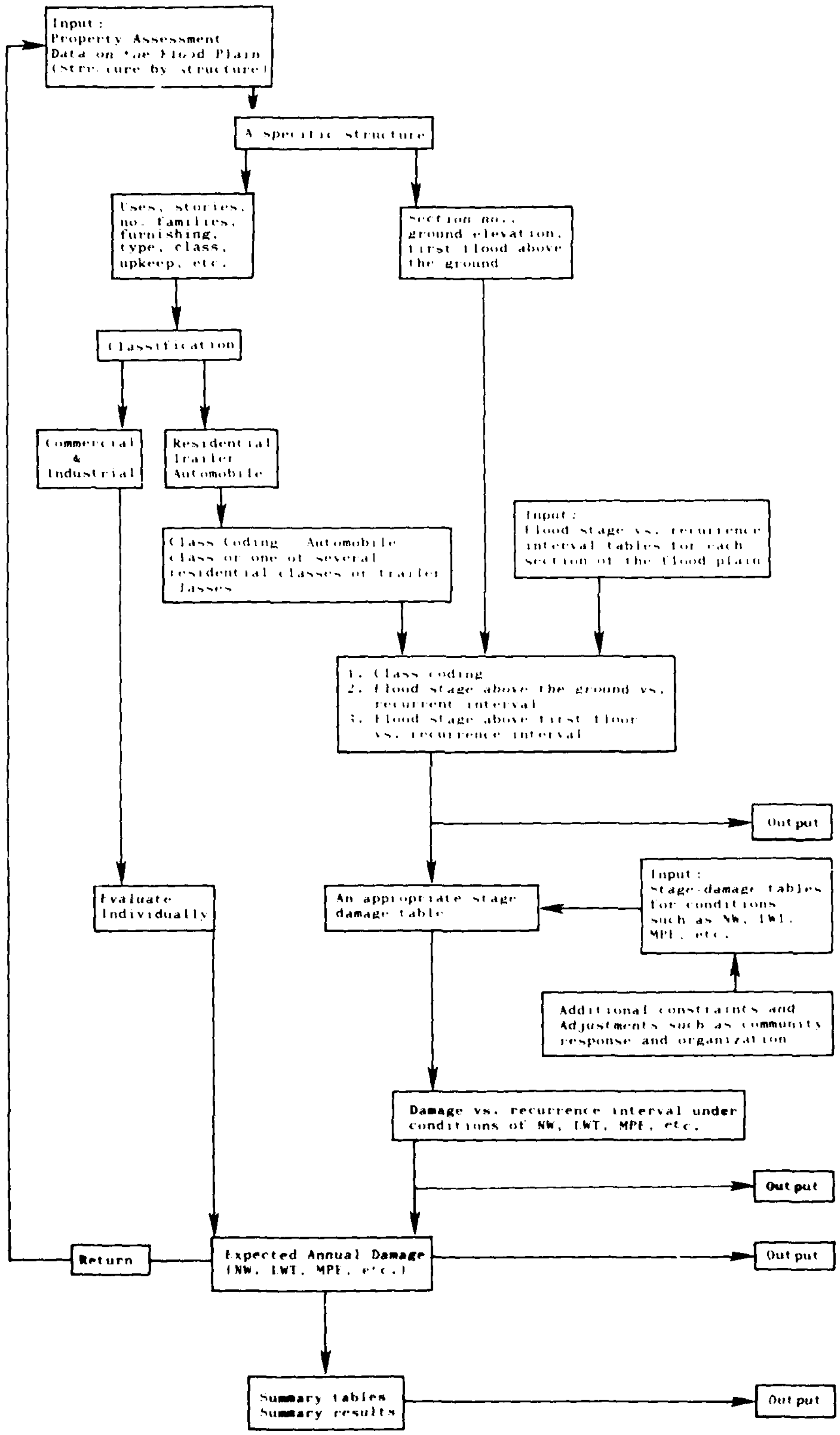

FIGURE 1
COMPUTATION PROCEDURES

The realism of equating no protective action to the "no warning" case is also suspect with regard to its application to all situations. Except in unusual cases, at least some warning apart from a local system is likely to be available from generalized weather information issued by the National Weather Service, environmental cues, and observation or reports of flooding on the lowest flood plains. Again, numerous assumptions may be required in the generation of stage-damage curves for the structures under investigation. Moreover, the correctness of assumptions regarding such things as degree or response, preparedness and sensitivity to environmental cues may depend on the time elapsed since the last significant flood in the area, emphasis placed on continuing public information and other factors.

Notwithstanding these sorts of difficulties, the procedure for benefit analysis put forward by Day and Lee is useful. The critical obstacle to its fuller use is additional information from field examples to guide users in its judgemental aspects, particularly with respect to the types of potential benefits cited in Table 7.

CHAPTER 4

PUBLIC RESPONSE

The overall effectiveness of a flood warning and preparedness alternative stems from the combination of those activities for which formal arrangements have been made and the independent voluntary actions of the public at large. It was noted in Chapter 1 that one of the principal reasons for concern about the effectiveness of flood warning and preparedness alternatives was their dependence on appropriate public response to warnings. This chapter discusses the types of activities dependent on public response and the means of encouraging that response.

ACTIVITIES DEPENDENT ON PUBLIC RESPONSE

The governmental role in carrying out flood warning and preparedness alternatives usually includes responsibility for all of the important activities associated with operation of the flood recognition system, issuance and dissemination of warnings, and maintenance activities. Any activities of those types which are not performed directly by public officials and staff are likely to be done under their direction and in accord with arrangements worked out between the government and individuals or private organizations assigned responsibility. The accuracy of the flood recognition system and the speed of the warning dissemination process may sometimes be enhanced by information volunteered by members of the general public or by informal word of mouth distribution of warnings and those types of public participation may even be specifically encouraged. But flood warning arrangements seldom depend on them for success.

Preparedness plans differ significantly from warning arrangements inasmuch as they frequently include some activities which are to be taken by governmental forces and some which depend on individual actions by members of the general public for their performance. The division of responsibility for the performance of activities between the government and the general public can vary widely as well as the extent to which such assignments of responsibility are explicitly recognized and formalized.

As noted in Chapter 3, flood warning and preparedness alternatives should be comprehensive with respect to planning all of the response actions pertinent to achieving their objectives. The performance of participants in carrying out those actions should also be formalized to the extent possible and made binding. If this is done, the only actions dependent on voluntary response by the public are those for which binding arrangements either cannot be made or are impractical.

All of the preparedness actions to be performed by governmental organizations are subject to coverage under some type of formal arrangement. Thus, for example, decisions by school administrators or municipal hospital officials with respect to responding to warnings need not be left in the domain of voluntary public response. Even the role of certain quasi-public and private parties such as the Red Cross or local contractors who might be expected to assist need not be left to chance. Formal arrangements can be developed to provide for use of their facilities and equipment or for performance by them of particular tasks.

Those things that remain dependent on a voluntary public response are so because of one or more of the following reasons:

1. Specific arrangements for performance are impractical because of the large number of parties involved;

2. Authority is lacking to require performance; or

3. Capability is lacking to enforce required performance.

The two principal activities which depend on public response are evacuation and protection of private property. Of course local governments could adopt ordinances relevant to these matters. For example, an ordinance could require evacuation of certain areas pursuant to a declaration that some stage of emergency existed based on flood forecasts. But the most likely benefits of such an ordinance would be to: a) provide a legal basis for the forceful removal of parties who refused to evacuate voluntarily; and b) make clear to residents in affected areas that those who refused to obey a directive to evacuate would bear the liability for any costs or damages in the event rescue subsequently becomes necessary. There would obviously be little potential for prosecution of those who refused to obey the law and equally little chance that forced evacuation could be successful with more than a few people, especially in cases where warnings provided only minutes or a few hours for action. The same sort of enforcement problems would attend efforts to require by law that private parties take action to protect their property.

ENCOURAGING PUBLIC RESPONSE

Given the types of obstacles described in the foregoing section, the key to effective public response in the matters of evacuation and protection of private property is the provision of sufficient information so that a rational decision by individual members of the public in the protected area will lead to the desired action. This has direct implications for the construction and delivery of warning messages, content of preparedness plans, and educational and informational efforts.

Warning Messages

The warning message is the major means by which public response is generated. Of the many considerations affecting its makeup, the most important are clarity, credibility and impact of delivery.

Warning messages must clearly instruct the message recipient as to what actions are appropriate. The capability of conveying instructions depends first of all on the means used for the dissemination. Sirens and airhorns are particularly limited in this respect. If plans for their use are accompanied by a continual public information program, the use of patterns and tones of sound may serve to distinguish a flood from another emergency or to convey the seriousness or urgency of the threat. However, in most cases, use of the siren is intended only to awaken people or get their attention and cause them to turn on the radio or seek other sources of information about the nature of the emergency. And, of course, even strong educational programs are unlikely to reach transients in the community and certain segments of the area's permanent population.

Radio, television, announcements over public address systems, and person-to-person contacts enable delivering a more complete message. But the message must be carefully composed. The two following hypothetical messages illustrate poor composition:

> MODERATE FLOODING IS EXPECTED ALONG THE CASPER RIVER TONIGHT. RESIDENTS OF LOW-LYING AREAS SHOULD PREPARE TO EVACUATE.

> THE CASPER RIVER IS EXPECTED TO REACH A CREST STAGE OF 38 FEET AT LOUISBURG NEAR MIDNIGHT. BANKFULL STAGE IS 28 FEET. RESIDENTS OF LOW-LYING AREAS SHOULD PREPARE TO EVACUATE IF NECESSARY.

Neither message conveys much information useful to the average recipient in determining whether his or her location is subject to flooding, when the onset of flooding will occur, or exactly what should be done other than "evacuate." Compare those messages to the following:

> THE CASPER RIVER IS EXPECTED TO OVERFLOW ITS BANKS AT LOUISBURG LATE THIS AFTERNOON. FLOOD STAGES WILL INCREASE DURING THE EVENING AND CREST ABOUT MIDNIGHT. CREST STAGE WILL BE ABOUT 10 FEET OVER BANKFULL LEVEL. FLOODING WILL BE APPROXIMATELY 3 FEET HIGHER THAN THAT WHICH OCCURRED IN OCTOBER 1974. ALL AREAS BETWEEN THE RIVER AND CARROLLTON ROAD SHOULD BE EVACUATED. RESIDENTS OF MUMMERT ISLAND SHOULD EVACUATE BEFORE THE WHEELING CROSSING IS FLOODED. A RECEPTION CENTER HAS BEEN OPENED AT SNELL SCHOOL FOR EVACUEES.

The information presented by this sort of message is far more helpful to listeners in determining whether the message is intended for them, the extent of the threat, the timing of the threat, and the appropriate action to take. As might be necessary or useful, the message could also instruct the potential evacuees on steps to take to reduce property losses, the highest and safest routes for evacuation, and other points.

The weight given to a warning message by a recipient also depends to some extent on the credibility of its source. Studies show far more weight is given to warning messages attributed to highly respected organizations or individuals. Thus, the message described in the preceding section could be strengthened by attributing the prediction of flooding to the Corps of Engineers, National Weather Service or some well known state or local agency. Similarly, the direction to evacuate could be stated as coming from the local civil defense agency, the mayor or some other immediately recognizable source.

Warning messages can also be given importance and credibility by the manner in which they are delivered. The appearance of a uniformed police officer at the door with a message obviously gives impact to the message's content. Other means of showing official sanction of the warning message include its dissemination by public address systems on police and fire vehicles and use of police or other local officials for making announcements over radio or television instead of station personnel who happen to be on duty.

The importance accorded warning messages is also influenced by the context in which they are presented, particularly over radio and television. Announcements which are only summarized, treated in a casual manner, and sandwiched between regular programming are unlikely to generate much response. Special arrangements with radio and television station operators are usually necessary to assure proper handling of warning messages.

Warning messages also gain importance by repetition. Also, of course, a single reading of a lengthy message may not be sufficient for listeners to comprehend its total content. Repetition as applied to flood warning messages has two meanings including: a) repeated announcements of the message by a particular source; and b) announcement of the message through a variety of mediums. Caution is necessary to ensure exact coordination when using several mediums. Conflicting messages to the public destroy credibility, create confusion and lessen response.

Content of Preparedness Plan

The development of preparedness plans and the construction of warning messages which motivate action in accord with the plan must anticipate and answer the public's concerns about the desired action if they are to be effective. For example, many people can be expected to be reluctant to evacuate for one or another of the following reasons:

1. Concern over vandalism and/or looting of unattended homes or businesses;

2. Concern for safety of children at school and other family members away from the home;

3. Lack of a secure location for storage of any items which are temporarily relocated;

4. Lack of a safe and convenient destination; and

5. Lack of transportation.

Identification of the range of concerns likely to exist about evacuation or other desired actions gives insight into the necessary provisions of the preparedness plan and the required explanation of those provisions in warning announcements.

Educational and Informational Efforts

A variety of educational and informational efforts can be helpful in securing the public action desired in response to a particular flood threat. These activities can be divided into general educational and informational programs, provision of immediate pre-flood information, and provision of post-flood information.

General educational and informational programs conducted on a continuing basis are necessary to develop public awareness of the flood hazard and the flood warning system. They may also serve numerous other purposes such as explaining the meaning of particular warning signals, acquainting people with the actions expected of them during a flood emergency and providing information on how to protect property from damage.

Ongoing programs for general educational and informational purposes may include publication and distribution of brochures, direct mailings to owners and managers of properties in flood prone areas, inclusions of inserts in utility billings, public service spots on radio and television, and publication in newspapers of such things as maps of areas affected by various levels of flooding. General programs can also include more direct approaches such as public hearings, training sessions, and provision of technical assistance to property owners in planning contingency actions for damage reduction.

The most important item of information in the immediate pre-flood period is the warning message. If general educational and informational programs were 100 percent effective, that might be all that was required. However, it must be expected that a significant portion of the community only pays heed to such information when a crisis is apparent. And, of course, new residents in an area may not have benefitted from ongoing education and information about the flood threat. A need therefore exists for the provision of information and instructions in the immediate pre-flood period concerning the appropriate response to warnings. Among other items, such information and instructions might cover evacuation routes, safe destinations, summarization of the preparedness plan's provisions for security and safety of school children, means of damage reduction and suggestions of items to take when evacuating a home or business. The detail of such instructions and information and the means of their delivery depends on the time available.

Actions taken in the immediate post-flood period can be important for both safety and loss reduction. Information programs to encourage appropriate public response at that stage of a flood episode might deal with safe re-entry of flooded structures, salvage of damaged contents, decontamination of water supplies, vector control, disposal of debris, and other related items. They might also include information on the availability of temporary housing, making application for federal and other disaster aid, filing insurance claims, and sources of other types of assistance. Dissemination of this type of information poses fewer problems than the case of pre-flood information. After the flood, most individuals of whom a particular response is required are likely to be receptive to or seeking such information. With the exception of cautions about immediate dangers such as re-entry of flooded structures, simple availability of printed information sheets may be adequate.

DEGREE OF PUBLIC RESPONSE

The case studies described in Appendix A provide some information about the extent of public response to flood warnings which is to be expected. Based on that information, it appears that it is reasonable to expect 60 to 80 percent of the people in a threatened area to take some type of protective action the first time the warning system results in issuance of a warning. A higher percentage of participation, perhaps as much as 90 to 95 percent, is likely to occur in the next and following warnings if: a) the first warning proved to be accurate and those failing to respond suffered damages; and b) the period before the next flood is no more than a few years so that the memory of the previous experience is fresh.

However, it should be recognized in assessing the experience of the case study communities that each warning system described except that for Wise County, Virginia, was established following a disasterous flood. Some preconditioning, therefore, existed in most cases which made residents sensitive to the possibility of flooding. In those circumstances, the extent of participation experienced in the first use of the flood warning system might be somewhat higher than for a community which had not experienced serious flooding in several years.

CHAPTER 5

SUMMARY OF EXAMPLES

Appendix A describes six examples of flood warning systems in the United States. Each example is described with respect to the physical setting, nature of the flood problem and features of the area's flood warning system. Descriptions also address the views and experiences of local officials and others who are responsible for operation of the systems or depend on them for protection.

The several flood warning systems described vary widely in their organization and mode of operation. The most obvious difference between them is the approach taken to the flood recognition component. The means used range from predictions based on a few observations of precipitation to sophisticated computerized analysis of several types of data inputs. While other arrangements exist and still others could be conceived, those which are presented constitute a relatively wide cross-section of existing practices.

Some general observations are possible based upon the investigation of the example flood warning systems. These include:

1. Flood warning and preparedness programs in all of the cases investigated are seriously deficient in terms of measuring up to all of the desirable characteristics of protective systems described in previous chapters of the report. In particular:

    A. Excepting one industry which has developed a flood preparedness plan, all of the systems are unbalanced in that attention has been focussed on flood recognition and warning with little consideration given to development of formal response plans;

    B. None of the systems evidence design which provides the degree of detail or the explicit consideration of reliability and other criteria described in Chapter 3; and

C. All of the systems depend for their success almost exclusively on the voluntary cooperation of individuals, businesses, organizations and/or governmental agencies and little attention has been given to their formal implementation in a legal and institutional sense.

Notwithstanding their shortcomings, the systems investigated function adequately and, in some cases, have resulted in very large savings. This gives strong reason to anticipate that protective systems designed in more detail and which are more complete can be expected to be more effective.

2. Specific planning for preparedness increases the monetary benefits which can be obtained. For example, experience at the Sprout Waldron plant in Lycoming County, Pennsylvania and the flour mill near Elicott City, Maryland (Howard County) illustrate dramatic savings in the extent of losses resulting from flooding associated with Hurricanes Agnes and Eloise. The reduction of losses in these cases can be attributed directly to specific preparedness actions.

3. Warning systems need not be expensive or complex to be effective.

4. The benefits which can be secured from flood warning and preparedness programs are diverse and include:

   A. Reduction of hazard to life through:

      i. Timely evacuation;

      ii. Improved decision-making on release of employees from work and release and transportation of school children;

      iii. Action to prevent travel into hazardous areas;

      iv. Marshalling of manpower and equipment for rescue, medical attention, and other emergency services;

v. Emergency management, as appropriate, to continue or curtail operation of water, gas, electric and other utility systems;

B. Reduction of property damage through:

i. Movement of property to safe elevations;

ii. Protection in place of fixed equipment;

iii. Protection of structures by contingency measures;

C. Reduction of costs other than property damage through:

i. Minimization of business losses by speeding recovery;

ii. Better scheduling of emergency personnel;

iii. Reduced needs for flood insurance; and

iv. Avoidance of costs for unnecessary mobilizations of manpower and other emergency actions.

5. Even simple flood recognition systems can be highly accurate if properly designed.

6. Public response to warnings is not likely to be high immediately after initiation of a flood warning system if no special efforts such as those described in Chapter 4 are mounted. However, public response becomes very high after the first case of warning in which parties not responding suffer losses.

7. Flood warning and preparedness programs are adaptable to a wide range of situations in terms of physical setting, rapidity of the onset of flooding, nature of area at risk, and financial and technical capability.

8. Flood warning and preparedness programs can serve various purposes including such things as assisting in overall water management in non-flood periods, and as a core around which other disaster preparedness plans can be organized.

9. Flood warning systems can be successfully organized and operated under a variety of institutional arrangements including by general purpose governments, special purpose districts, and various combinations of governmental agencies and private sector entitites.

10. Flood warning and preparedness programs are a useful supplement to flood control works and should be part of all well-conceived flood plain management programs.

APPENDIX A
EXAMPLES OF LOCAL FLOOD WARNING SYSTEMS

The simplest flood warning systems are built around a single flash flood alarm that serves to alert local officials that upstream water levels are increasing so that an observer can be dispatched to investigate. The most popular systems are those which enable predicting floods based on rainfall and or stream-level observations provided by volunteers. The major reason for the popularity of the latter types of systems is that a relatively high level of performance can be secured for a moderate cost. Fully automated and computerized systems are gaining rapidly in popularity, however, in spite of their higher cost. The reasons for this include their speed, accuracy and capability to handle complex hydrologic and hydraulic situations. Some systems of this latter type also have sufficient capability to serve as tools for day-to-day water resources management.

There are presently several hundred local flood warning systems of these various types being operated in the United States by city and county governments, special purpose districts and other organizations. They differ greatly in their cost and details of operation as well as in their basic type. This appendix describes 6 flood warning systems which illustrate some of the major approaches to flood recognition and the costs associated with each. Descriptions of each system are followed by statements of the views expressed by local officials about the effectiveness of the system used in their area.

HOWARD COUNTY, MARYLAND

Howard County is located immediately northeast of Baltimore, Maryland. It has an area of 250 square miles. At present, lands in the county are largely in agricultural, forest or other open space uses. However, urbanization is proceeding rapidly in the east-central part of the county because of its proximity to both the Baltimore and Washington, DC metropolitan areas. Population in Howard County grew from 62,394 in 1970 to an estimated 99,000 in 1975. The 1990 population is expected to be more than 200,000.

A large portion of Howard County is bordered by the Patapsco River on the north and east and by the

Patuxent River on the west and south (Figure A-1). Within the county, the Little Patuxent and Middle Patuxent Rivers have a combined drainage area of about 166 square miles. There are also numerous minor tributaries to all of the principal streams.

The county is situated on the Piedmont Plateau. The area is characterized topographically by rolling hills with gentle slopes, except along the major streams, where rejuvination has produced comparatively steep-walled valleys. Flood plains in the area are relatively narrow.

Mean annual precipitation in Howard County is about 40 inches. The distribution of precipitation throughout the year is fairly uniform with July and August being the wettest months. Thunderstorms occur in the area on an average of about 30 days per year. The area is subject to intense rains from hurricanes and other tropical storms.

Floods have occurred frequently in Howard County. Recent major floods occurred in 1933, 1946, 1952, 1956, 1967, 1972 (Hurricane Agnes) and 1975 (Hurricane Eloise). Flooding causes damages to roads and bridges, industrial and commercial facilities, and residences. It also poses serious problems of safety and numerous lives have been lost in past flooding. The major damage centers are Ellicott City (1970 population of 2,000), Elkridge (1970 population of 2,100) and several residential developments scattered through the eastern portion of the county.

The worst flood on record was that caused by rains from Hurricane Agnes in 1972. Much of the downtown portion of Ellicott City was inundated then to a depth of several feet. Due to the almost total loss of business stocks and other damages, many of the flooded businesses were closed for several months.

Flood Warning System

Following the flooding associated with Hurricane Agnes in 1972, the National Weather Service recommended development in Howard County of a local flood warning program. Local officials agreed with the recommendation and the present program was implemented through the cooperative efforts of the Howard County Office of

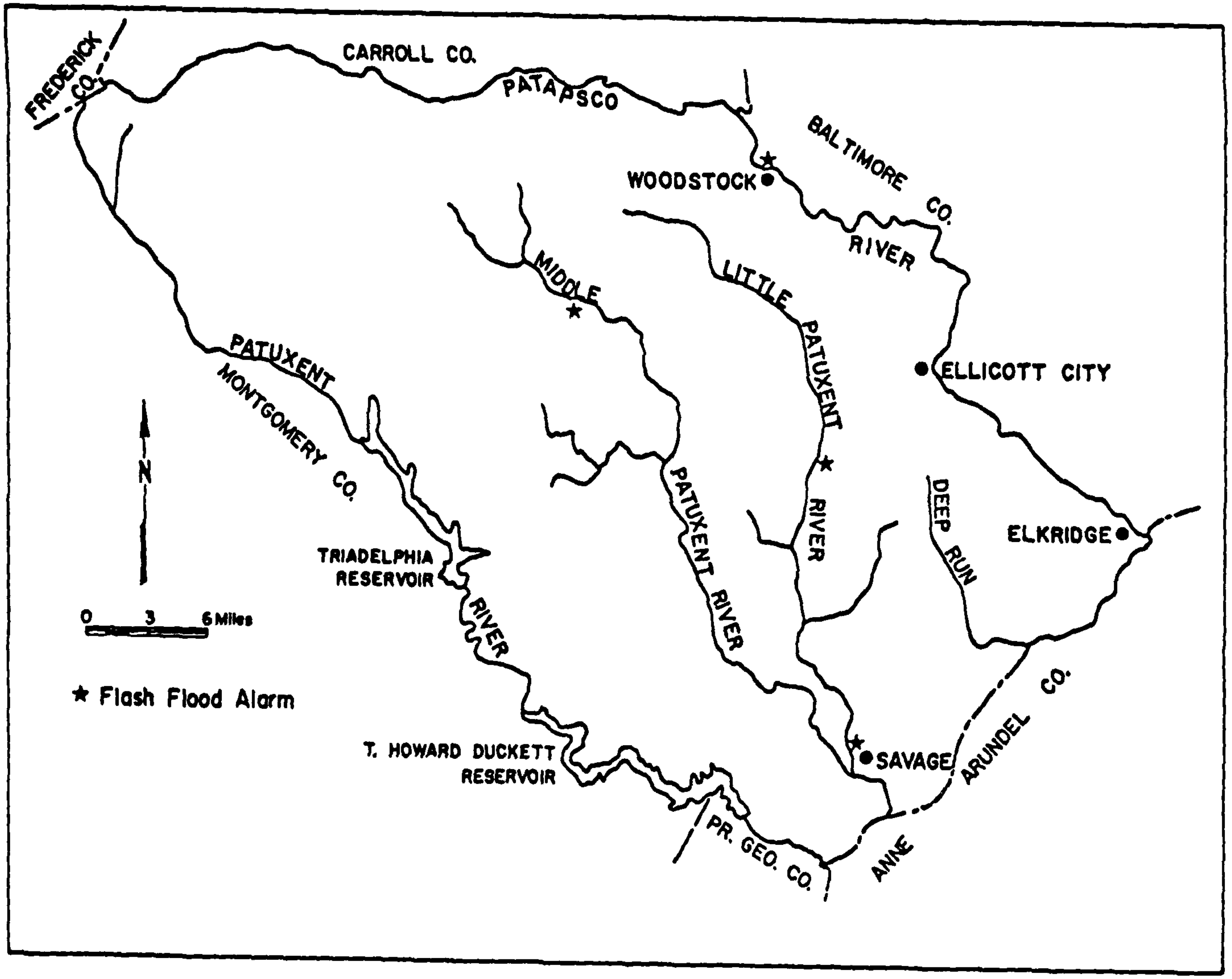

FIGURE A-1. HOWARD COUNTY, MARYLAND

Civil Defense, Howard County Central Alarm Communications Center, Howard County Department of Public works and National Weather Service.

The flood recognition system consists of four flash flood alarms, several river-level gages to be read by observers and a network of inexpensive plastic precipitation gages located at the county's nine fire stations. In addition, the Communications Center and the Civil Defense Office, which are located together, receive information from the National Weather Service through the Maryland State Police teletype circuit. Figure A-2 illustrates schematically the operation of the flood recognition system. A flash flood alarm is also located at the county's wastewater treatment plant to warn plant personnel of rising waters which could flood the access road to the plant.

The flash flood alarms provide continuous monitoring of conditions on major streams in the county. The remainder of the flood recognition system is activated whenever one of the flash flood alarms indicates at the Communications Center that water levels have risen significantly. The Communications Center alerts the Civil Defense and Department of Public Works personnel that a flash flood alarm has activated and notifies the county's fire stations to begin making hourly reports on precipitation and half-hourly reports on stream stages at selected river-level gages. Standard operating procedures also call for rainfall measurement and river level reporting by fire department personnel to begin automatically any time 1 inch of rain in 2 hours is noted at a fire station location.

Precipitation data provided through the system is used to determine whether increases in observed stages at key points along the stream are to be expected and or whether monitoring of streams should be continued. As needed, reports on other river-level gages are requested to add detail and confirm the available information. The predictions of impending flood stages for major damage centers are made by the Department of Public Works based on the flood stages reached at upstream points.

The warning system makes it possible to provide Ellicott City, Maryland about 6-8 hours notice that some flooding will occur and 2 1 2 hours notice of the expected crest stage. For the community of Elkridge,

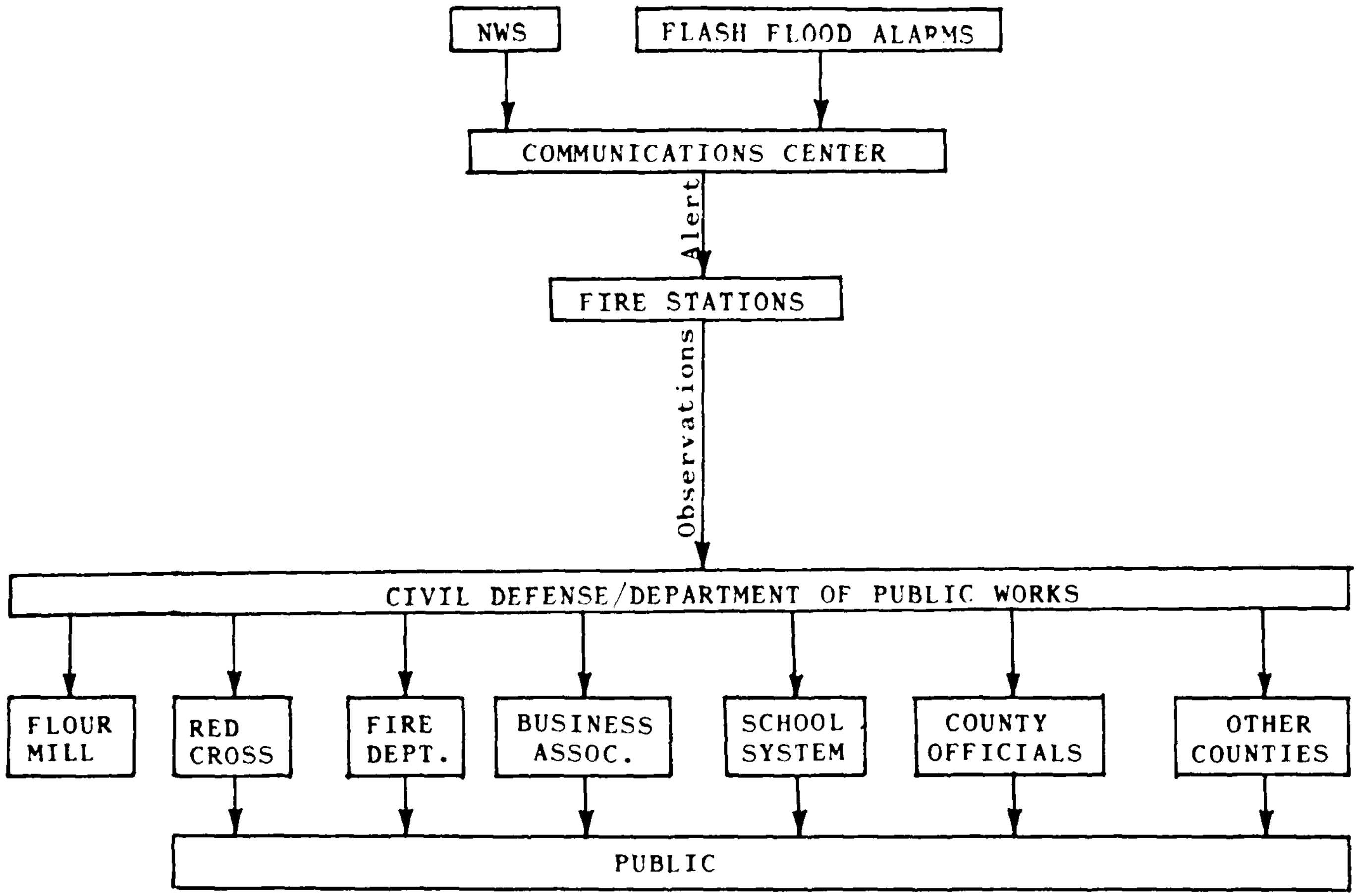

FIGURE A-2
SCHEMATIC ILLUSTRATION
OF
HOWARD COUNTY, MARYLAND
FLOOD WARNING SYSTEM

Maryland, which is downstream of Ellicott City, these warning times are extended about an additional 2 hours. Depending on their location, other developed areas in the county receive generalized warnings based on information from the National Weather Service or more specific warnings based on local information that flooding will occur, but without prediction of a specific crest level.

Flood warnings generated through the system are issued to the fire and police departments, county officials, the president of the Ellicott City Business Association and to several downstream counties. Each fire station maintains a listing of all residences in flood-prone areas within its district. Warnings are disseminated to occupants of affected areas by sirens on emergency services agencies' vehicles and by knocking on doors. The Ellicott City Business Association alerts business proprietors in Ellicott City. In addition, the Red Cross and county school system are issued warnings so that advance arrangements can be made for sheltering and feeding evacuees. One installation, a large flour mill located in Baltimore County across the Patapsco River from Ellicott City is provided warnings by a special arrangement between the mill and Howard County.

The original cost for purchase and installation of the flash flood alarms was approximately $3,000 each. National Weather Service provided two of the flash flood alarms and all of the precipitation gages. Howard County bought the remaining two flash flood alarms and installed the river-level gages. Maintenance of the flash flood alarms costs about $500 annually for each unit. Operational costs for the four flash flood alarms include telephone and electrical service. Charges for electrical power are about $24 annually and are paid by the county. Charges for the telephone lines connecting the four alarms with the Communications Center total approximately $3,200 annually which is paid for half by the county and half by federal funds passed through the State. There are no costs associated with operation and maintenance of the plastic precipitation gages except occasional replacement of a gage broken due to freezing of collected rainfall. About one-half man-day per month is required for overall maintenance and testing of the system.

Views of Local Officials

Howard County Civil Defense. The operation of the warning system provides both safety for residents in the county and opportunities for reduction of property damages. Safety oriented actions which are taken based on information from the warning system include evacuation of flood prone areas, decision-making on release of children from school, curtailment of gas, water and electrical utility service in areas to be flooded, placement of police and fire crews on standby and provision of advice to travelers. Damage reduction activities enabled by the plan include evacuation of vehicles and contents of residences and businesses, protection of livestock in rural areas, movement of harvested crops, and protection of public equipment in Baltimore County. One of the biggest instances of damage reduction results from relocation of finished products at the flour mill. The reduction of safety problems and property damages also reduces public costs for clean up, rescue, decontamination of water mains and other items. Important side benefits of the system are the sense of security provided to county residents and their confidence that local government is taking action to protect them.

The warning system is thought to be very reliable since all communications by telephone are backed up by radio and several persons can make flood forecasts if necessary. A senior dispatcher familiar with operation of the system is on duty at the Communications Center around the clock. Flash flood alarms incorporate fail-safe devices but, in any event, have been 100 percent operational at all times since their installation. Personal contact by firemen with residents needing to evacuate assures warnings are received and understood. Accuracy of the flood warning system is very good with respect to both the predicted crest stage and the estimated time of flooding at various areas.

Public reaction to the system has been excellent including several very favorable news stories pointing out its benefit. Both local officials and members of the general public call frequently for updates on conditions when rain is occurring. The executive branch of county government and the county council have looked favorably on financing the system, including a willingness to fund all operational costs in the event federal cost sharing funds were not available. Public credibility of the system is evidenced by the fact that there was a high response to warnings of flooding from Hurricane Eloise in 1975. As a result, moving of equipment and contents of structures made a highly significant reduction in flood losses.

Ellicott City Business Association. Ellicott City was totally unprepared for the 1972 flooding which resulted from Hurricane Agnes. Without any warning, merchants did not anticipate flooding and made no attempt to move goods from their business places. Almost all business stocks were lost and about 8 months were required for the city to recover and for business to operate normally. In contrast, a warning was received about 11:00 o'clock the night before flooding from Hurricane Eloise. About 75 percent of the merchants in the flood plain responded to the warning by moving their property, assisted by volunteers from the community. By the time flooding began at 4 or 5 o'clock in the morning, all of the merchants who had made the effort had saved a large part of their stock. Stores were opened for business within a couple of weeks.

Experience during the evacuation showed most small shops could be cleared of valuable items in about 45 minutes. Merchants in the community are now very sensitive to the flood threat and an even higher turnout is expected the next time that warnings are issued. The Business Association believes the system is very reliable and accurate and goes into action to spread warnings as soon as they are received.

In addition to the reduction of flood losses, the warning system paid off through the saving of lives and taking the tension out of flood situations. The flood warning system is thought to be a very worthwhile investment which merchants would rather have than any other insurance on their business.

Howard County Department of Public Works. The flash flood warning system has been an excellent investment for Howard County. It has changed both the damages and dangers posed by floods. Floods previously occurred unexpectedly or with very little warning. Now, most flood prone areas are notified well in advance of an oncoming flood.

Thirty homes were completely inundated during storm Eloise in 1975. However, due to the early warning provided by the system, the people who lived in these homes were all evacuated. Early warnings enabled merchants in Ellicott City to move most of their stock to high ground before the flood and enabled preparation for the flood by the Savage Wastewater Treatment Plant.

Accuracy of the system is excellent. The flood crest elevation which was predicted during Eloise was within a half foot of what actually occurred and the time of the crest was correct to within one hour.

NEW BRAUNFELS, TEXAS

New Braunfels, Texas (1970 population of 19,500) is located in the southeastern portion of Comal County, about 30 miles northeast of San Antonio. The city lies on and adjacent to the flood plains of the Guadalupe River and two of its tributaries, Comal River and Blieders Creek. The Guadalupe River is largely controlled about 30 river miles upstream from New Braunfels by Canyon Dam, a Corps of Engineers structure which stores water for both flood control and conservation purposes. Flooding in New Braunfels and in downstream areas results from runoff from some 87 square miles of drainage areas along the Guadalupe River below Canyon Dam and from the approximately 130 square miles of area drained by the Comal River and Blieders Creek (Figure A-3).

Annual rainfall in the Guadalupe River Basin varies from about 27 to 37 inches. Rainfall is distributed fairly well throughout the year. Thunderstorm rains occur during all months but mainly in the summer and are a significant part of the annual precipitation. Later summer and autumn rainfall is occasionally increased greatly by tropical storms or hurricanes that move in on the lower Texas coast and curve northward.

Flooding occurs frequently in the area and causes moderate to severe damages to agricultural lands and to urban developments in New Braunfels. Small overflows occur at least annually in New Braunfels and cause minor damage to yards, streets and crossings. Larger floods that cause significant damage to urban developments occur on the average of every 9-10 years. Recent

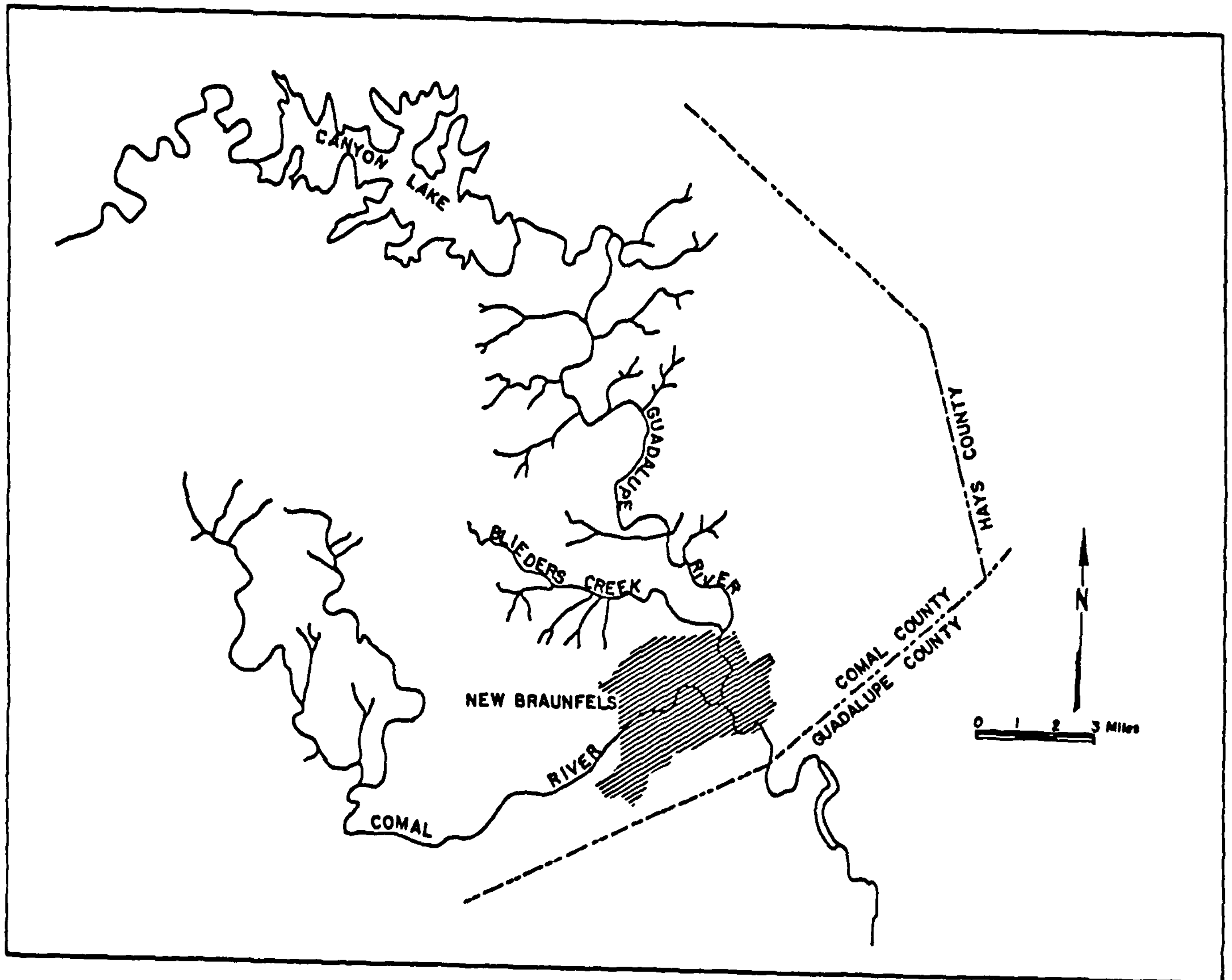

FIGURE A-3
AREA OF
NEW BRAUNFELS, TEXAS

damaging floods occurred in 1932, 1935, 1936, 1952, 1953, 1957, 1972, and 1977.

Prior to the 1972 flood, the local radio station had a teletype unit linked to the NOAA Weather Wire circuit. Police also routinely observed the level of streams in the community when heavy rains occurred. However, the city had no arrangements for dissemination of warnings and no prepared plan for responding to warnings. It was assumed that whatever emergencies arose during a flood could be dealt with successfully by extemporaneous action.

Flash flood warnings for the New Braunfels vicinity which could be provided by the National Weather Service were necessarily generalized due to a lack of detailed information on rainfall occurring in the drainage areas between Canyon Dam and the city. Since flooding could begin in New Braunfels shortly after the beginning of intense rains in the upstream areas, even the generalized warnings which were issued left little time for evacuation of persons or protection of property in low-lying areas.

During the night of May 11, 1972, intense rains caused a severe flash flood along the Guadalupe River, Comal River and Blieders Creek. Seventeen people were killed at New Braunfels by the flood and damage in the community was estimated to be approximately $25 million to private property, $2-3 million to public property, and an additional large but undetermined amount due to damage and destruction of streets and bridges. Over a year was required for the community to repair flood damages, restore all services and resume normal operations. Some 150 jobs were lost permanently as a result of the flood when a factory which had sustained heavy losses decided to close rather than make the repairs necessary to resume operations.

Information which was available at the time on rainfall prior to the 1972 flood indicated about 7 inches of rain had fallen in New Braunfels and 5 inches of rain had fallen at Canyon Dam. Estimates were later made that up to 16 inches of rain had fallen in the area between Canyon Dam and the City.

A flash flood warning was issued by the National Weather Service for several counties at 8 p.m. which stated:

A flash flood warning is in effect until midnight central daylight time for persons in Bexar, Bandera, Real, Kerr, Kendall, Comal, Medina, Frio, Atacosca, Wilson, Karnes, Guadalupe, and Gonzales counties in Texas. Heavy rain was indicated by radar north of San Antonio and other heavy rain was reported by the sheriff's office in Atacosco County at 7:45 P.M. central daylight time. The heavy rain will be moving northward over these counties tonight and flash flooding is likely. Persons should be alert throughout tonight for possible flooding along streams and low-water crossings.

A subsequent more specific warning for Guadalupe and Comal Counties was issued at 11:30 p.m. Flooding began along smaller tributaries in the New Braunfels area at about 11:30 p.m. and along the main streams at about 12:30 a.m.

While the warnings issued by the National Weather Service reached New Braunfels, that area commonly receives frequent severe weather and flash flood warnings and those received did not cause a major response to be undertaken. Lack of response was attributed to the expectation of protection by Canyon reservoir, disruption of communications by the storm and lack of realization of the huge magnitude of the impending flood.

As a result, people were largely unprepared for the flooding. Even after it was recognized that a flood of serious dimensions was imminent, dissemination of warnings and other responses which could have saved lives were handicapped because early flooding disrupted electrical service through much of the community.

Flood Warning System

Implementation of the flood warning program now protecting the New Braunfels area was begun immediately after the 1972 flood. The principal parts of the program are illustrated in schematic form in Figure A-4. They include:

1. Radio communications club with 55 mobile units and two base stations:

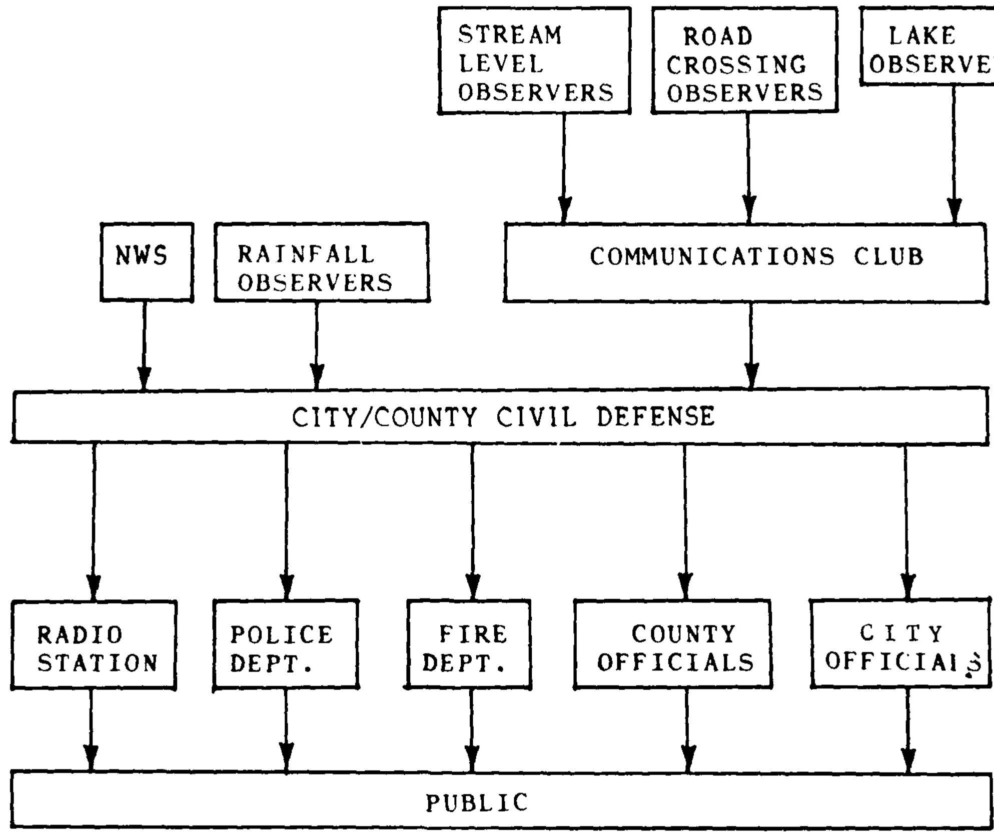

FIGURE A-4
SCHEMATIC ILLUSTRATION
OF
NEW BRAUNFELS, TEXAS
FLOOD WARNING SYSTEM

2. Network of 10 rainfall observers equipped with plastic rain gages supplied by the National Weather Service; and

3. A flood forecasting system prepared by the National Weather Service which relates rainfall to expected stream stages.

The measurement and reporting of rainfall by observers is activated by the New Braunfels and Comal County Civil Defense Coordinator upon receipt of information from National Weather Service by teletype, radio or telephone that heavy rains are expected. Standard operating procedures also provide for the flood recognition system to be activated any time an observer notes 2 inches or more of rain at his location. Observations are telephoned to the Emergency Operating Center where forecasts are prepared and periodically updated.

Members of the radio communications club are dispatched to observe the rivers and creeks in the area. As needed in the event of failure in telephone service between observers and the Emergency Operating Center, mobile units are also dispatched to rainfall observer locations to transmit rainfall data.

Based on predicted flood levels, the Civil Defense Coordinator issues warnings to elected officials of New Braunfels and Comal County, New Braunfels police and fire departments, the radio station serving the area, and several downstream towns. Warnings are disseminated to the public by radio, use of mobile public address systems on police and fire department vehicles and by door-to-door contact.

Members of the communications club carry their own insurance at an annual cost of $4.65 per person for $10,000 life insurance and $1,000 medical insurance. The communications club has also been licensed as a Civil Defense Rescue Squad. Once qualified for use of surplus government property, the club obtained low-band radios for $30 each, expended an average of $120 each to put radios in servicable condition and provides them to members at the club's expense. The club has two base stations and two antennas, one linked by telephone to a base station located at the Emergency Operating Center.

The original cost to local government for the flood recognition system was approximately $100 for installation of a dedicated telephone line linking the Emergency Operating Center, County Sheriff and radio station. Ten rain gages costing a total of $140 were furnished by the National Weather Service. The continuing costs for system operation and maintenance are approximately $250 annually for telephone line charges and toll telephone charges for calls from rainfall observers, $25 of which is matched annually by the State using federal funds.

Staff time to operate the flood recognition system is estimated to be 400 hours annually. Of this time, approximately 130 man-hours are devoted yearly to preparatory actions, practice and training of participants and the remainder for actual operation of the system during a flood threat. Since its inception, the system has been used some 15-20 times to predict flows when a flood threat existed.

Apart from their participation in the flood prediction system, rainfall observers are separately activated about 20-30 times annually to provide rainfall information to the radio station for local weather reports. This frequent use of the observer system negates the need for continuing training and practice. The Civil Defense Coordinator holds two meetings annually with the communications club for coordination and the National Weather Service inspects precipitation gages about once a year to assure their satisfactory condition.

Reliability of operation of the flood recognition system is provided through redundency of communication links, observation of upstream water levels to confirm impending flooding and availability of multiple persons capable of interpreting rainfall data and predicting flood heights. Evacuation is based on visual confirmation of flooding in upstream areas by observation of staff gages by members of the communications club. Altogether, the system adds about 30 minutes to the warning time which would otherwise be available. All pertinent city departments have standard operating procedures for response to flood warnings which are coordinated through a joint city and county Civil Defense Emergency Plan.

Views of Local Officials

New Braunfels and Comal County Civil Defense Agency. The largest value of the system is in extending the warning time of floods from practically zero up to 30 minutes, which is enough to warn and evacuate low areas and save considerable property. The value of warning time was made obvious in 1972 by the difference between the large loss of life at New Braunfels and the loss of only 1 life in heavily populated floodplain areas downstream which received warnings issued after New Braunfels began to flood. The second major value of the system is the confirmed information on flood severity which eliminates both overreaction and false alarms.

The advance warning of floods is used to accomplish evacuation of dangerous areas, move city equipment to safety from its normal storage area on the flood plain, and bring emergency services in the area to an increased state of readiness. It is estimated that the opportunity to move city equipment before a severe flood would result in a reduction of damages of about $1 million, almost half of all identified public losses in the 1972 flood. Altogether, it is estimated that the advance warning would enable a 25 percent reduction in the total damages that would otherwise occur in a severe flood as well as shortening the time required for restoration of services. In terms of the investment made in establishing and operating the system, "a return of 1,000 times over is no exaggeration."

To date the system has encountered no problems of any type in its operation except difficulty in accurate estimation of river stages by members of the communications club. This was rectified by placement of staff gages at various river crossings. In addition to floods, the communications club is available for use in other emergencies and the frequent use of both the communications club members and the rainfall observer network minimizes any need for training.

The system is viewed as being "literally 100 percent sure of operation and very accurate." The existence of the system is viewed as a distinct plus by city officials and supported by both them and the public. One advantage of the system is its role in making residents aware of the flood threat as a contribution toward decisions about land use in flood plain areas. The public is aware of and makes extensive use of the system, calling frequently when conditions suggest a flood might be in the making.

The flood warning system is considered to be the "keystone" of the overall civil defense program and the activity around which plans for other emergencies are organized. If the system did not now exist, the "highest priority" would be given to its establishment.

New Braunfels Police Department. The direct benefits to the Police Department of the early warning provided by the flood warning system is the opportunity to begin evacuation, make arrangements for traffic control, prepare emergency housing and activate the Emergency Operations Center to fully operational status.

The 30 minutes of early warning saves money in a variety of ways. The chance to move public property can mean a "tremendously large" savings. In addition, the warning system helps in setting up manpower both to assure adequate staff is on duty and to avoid unnecessary overtime. The system enables avoidance of overreactions to flood threat situations which would discredit emergency warnings in general and lead to a false sense of security. Another benefit of the combined warning system and response plan is the elimination of chaos and "65 to 85 percent of the mistakes which are made when it's necessary to act without enough time to think." Even the short warning time which is available enables evacuating a substantial amount of personal property from homes and businesses. The availability of specific information also enables giving aprehensive people better answers about what to expect.

The warning system is viewed as an excellent investment for which practically no expense is required. The system is well known to elected officials and supported both by them and the general public.

New Braunfels Fire Department. Early warnings provided through the flood warning system are used by the Fire Department to identify problem street crossings and underpasses and prepare alternate routes for carrying out fire fighting, warning and rescue. Warnings are also used to alert downstream communities of the coming flood.

The warning system is thought to be very valuable through enabling people to move vehicles and other personal property which would otherwise be lost. The expressed view is that the required investment is "well worthwhile and any community with a flood problem should find the money somewhere and put in a warning system."

New Braunfels City Manager. The flood warning system and preparedness plan provide "outstanding coordination" that aids the city in being "ready for any eventuality." Savings due to the system are "up to untold millions depending on severity of the flood." The system is used frequently, and well supported by the community's elected officials and the general public. The city administration has no concerns at all about liability or other problems resulting from operation of the system or action based on the warnings which are generated.

SANTA YNEZ RIVER

The Santa Ynez River rises in the San Rafael Mountains near the eastern boundary of Santa Barbara County, California. The river flows westerly through a series of valleys, discharging into the Pacific Ocean at Surf, California (Figure A-5). The Santa Ynez watershed is roughly rectangular in shape with an east-west length of about 90 miles and a north-south width varying from 8 to 20 miles. The watershed has a total area of about 900 square miles.

The upper half of the Santa Ynez watershed is characterized by narrow valleys and steep, rugged slopes. Flood plains in the upper watershed are sparsely developed and much of the land is wilderness area included in Los Padres National Forest. The lower portion of the watershed is characterized by broad flat valleys flanked by rolling hills. Developments in the lower valley which are subject to flooding include a portion of Vandenberg Air Force Base, a small portion of the city of Lompoc (1970 population of 25,284), commercial and industrial facilities in the suburban

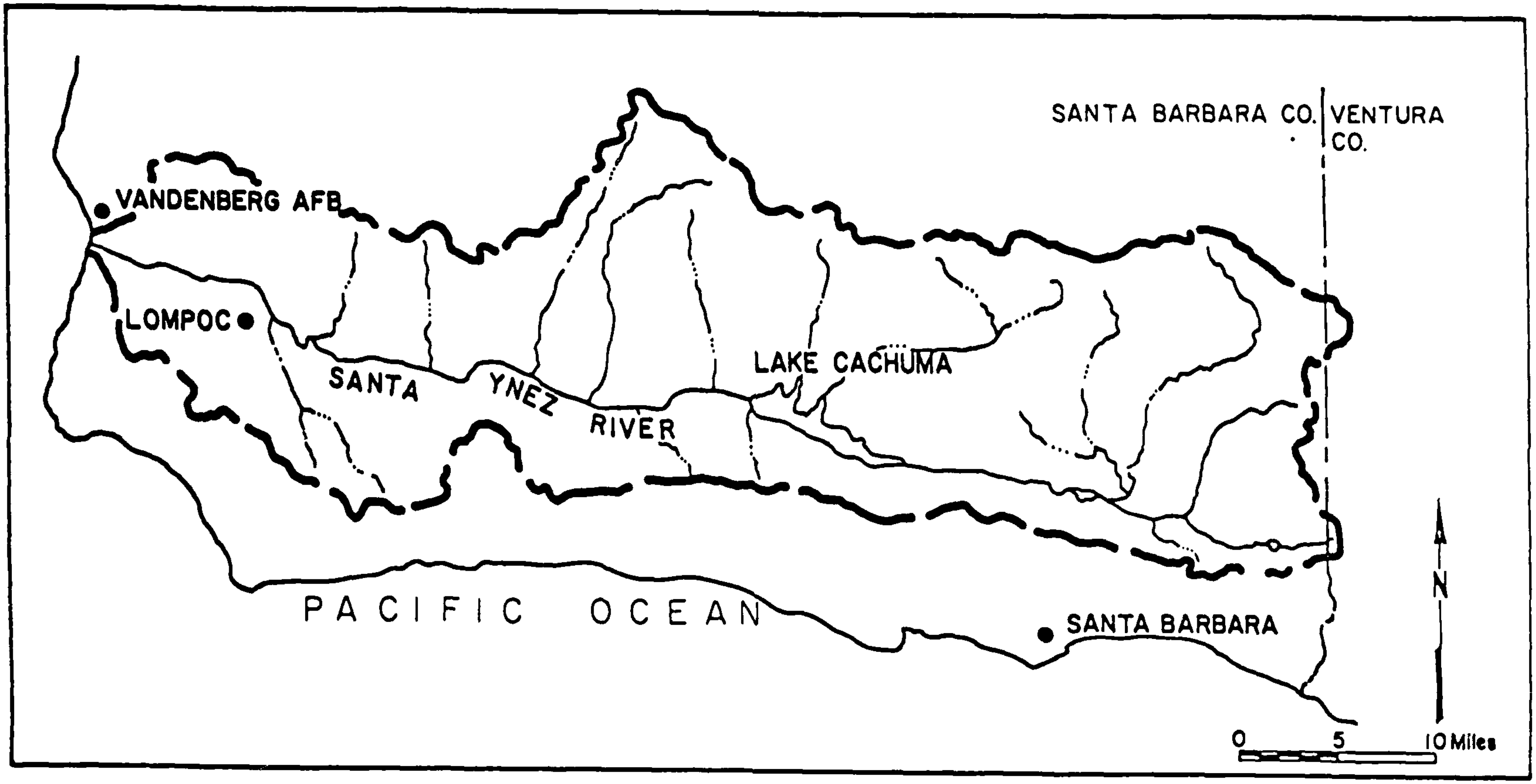

FIGURE A-5. SANTA YNEZ RIVER WATERSHED, CALIFORNIA area around Lompoc, Southern Pacific Railroad facilities and agricultural property. The economy of the area depends heavily on agriculture and tourism at present. However, much of the recent and expected future growth is related to settlement in the area of personnel associated with Vandenberg Air Force Base or related missile and space programs.

Mean annual precipitation in the watershed ranges from about 11 inches in the lower reaches to about 45 inches in the higher elevations of the watershed. Rainfall intensities of 2 inches per hour may occur. The greater part of the annual rainfall occurs from November through April. Flooding in the watershed is usually the result of protracted storms of four or five days duration that occur in the period from December through March. Some snow occurs in the higher mountains but it is not a significant factor in the flooding problem.

There are three dams of significant size in the watershed. Juncal, Gibralter, and Bradbury (Lake Cachuma), all of which are located on the river's main stem. Bradbury Dam, built and operated by the U.S. Bureau of Reclamation, is the largest of the three dams and is capable of storing about 205,000 acre-ft. of water, exclusive of surcharge. All of the reservoirs are operated for water supply and conservation purposes and only Bradbury has sufficient capacity to provide incidental flood control benefits to downstream areas. Operating procedure for Bradbury Dam requires impoundment of flood waters until the reservoir is full and then release of water at a rate approximately equaling inflows. Drawdown of the reservoir in anticipation of incoming flood flows is not permitted since flood control is not an authorized purpose of the facility.

Floods occur fairly frequently in the Santa Ynez watershed. They usually rise to their peak within 24 hours after intense rainfall begins and subside within a day after passage of the crest. Historical records indicate nearly 20 significant floods have occurred in the 51 year period of 1907-1978. A flood occurring 20-26 January 1969 was unusually large, having an estimated return interval of approximately 50 years. Two other floods of large magnitude also have occurred including one in 1907 which is thought to have exceeded the 1969 flood in peak discharge.

Damages resulting from floods in the watershed include destruction of agricultural buildings and fences, loss of livestock and crops, road and bridge losses, erosion, loss of agricultural and non-agricultural equipment, disruption of utility services in Lompoc, damage to railroad facilities and losses incurred at Vandenberg Air Force Base. Flood losses at Vandenberg Air Force Base which have occurred include disruption of communications and transportation, inundation of buildings housing computers and other expensive equipment, destruction of sewage treatment lagoons and erosion. Flooding also poses a threat to life along the floodplain throughout the length of the Santa Ynez River and flooding of Vandenberg Air Force Base is detrimental to national defense. The principal losses caused by the January 1969 flood were estimated to be in excess of $5.9 million including about $3 million at Vandenberg Air Force Base, $1.2 million to roads and bridges, $1 million to agriculture and $.7 million to railroads.

Flood Warning System

Implementation of the Santa Ynez River flood warning program was begun shortly after the January 1969 flood. The program was developed by the Santa Barbara County Flood Control and Water Conservation District. Figure A-6 shows a schematic illustration of the program.

The flood recognition system portion of the program includes automatic collection of data from 10 precipitation stations, 3 reservoir level gages, 10 gages on flood gates at Gibralter and Bradbury Dams, and 1 stream stage gage on the Santa Ynez River located at Lompoc, California. The data collection system provides for three modes of operation including automatic reporting on a "change of status" basis, interrogation by telephone, and automatic reporting on an elapsed time basis. All data transmissions are over dedicated telephone lines to the District's offices in Santa Barbara, California. Collected data may be either printed directly by teletype or entered automatically into a NOVA 12 mini computer system for analysis and reduction before printing. Processed information on precipitation and reservoir releases may be input into a watershed model operated on a Hewlett

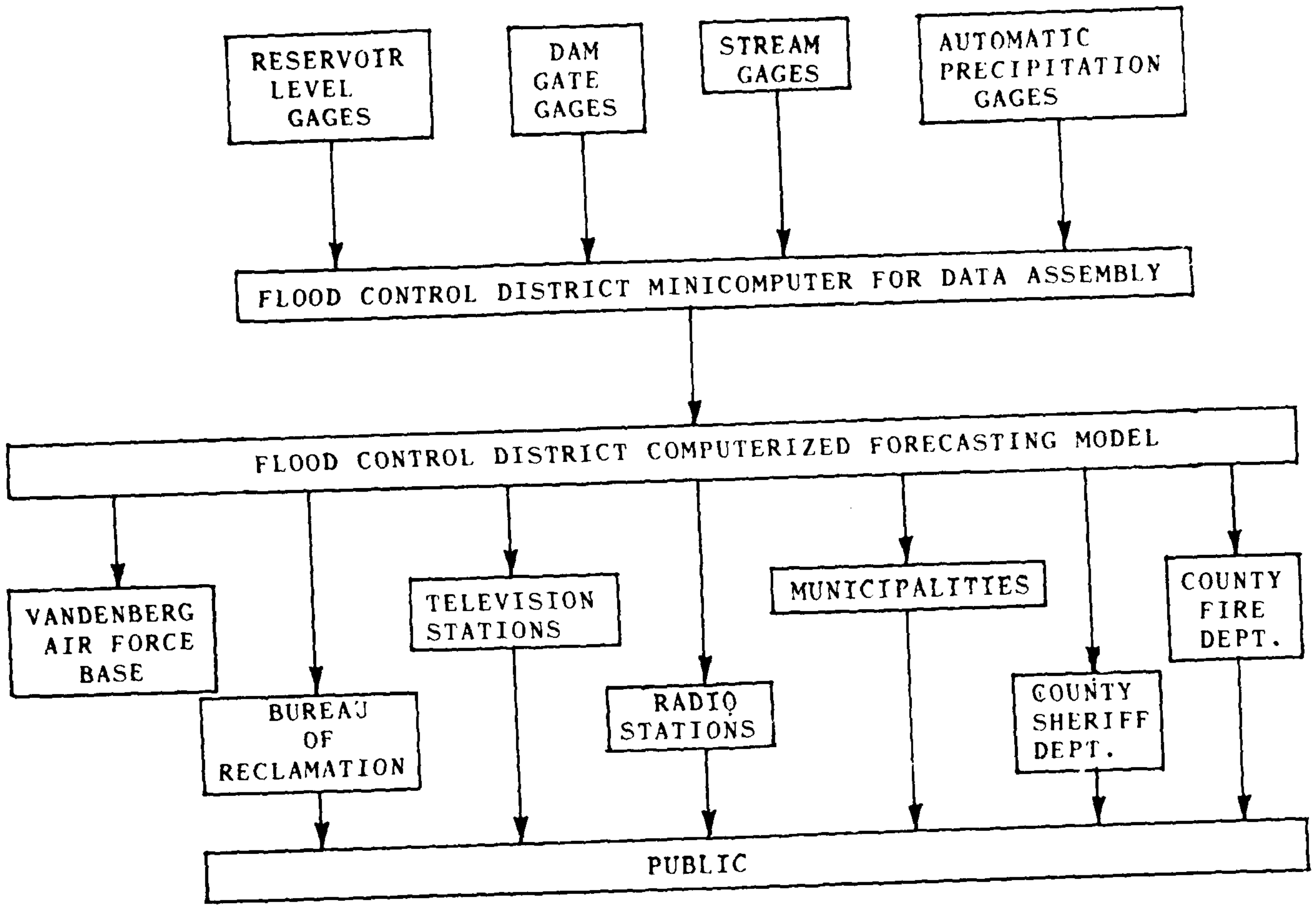

FIGURE A-6
SCHEMATIC ILLUSTRATION
OF
SANTA YNEZ RIVER
FLOOD WARNING SYSTEM

Packard 9830 computer for prediction of flows at various points in the watershed, including inflow to Bradbury Dam.

Based on predicted flows, the District issues warnings in accord with an emergency procedures manual. The manual specifies actions to be taken and parties to be contacted for each of several predicted flow levels for various portions of the watershed. The emergency procedures manual also includes directions for action in event of sudden failure of Bradbury and other dams in the watershed, standardized warning messages, and maps showing areas of the watershed inundated by various flows.

The primary recipients of flood warnings issued by the District include the Santa Barbara County Sheriff, City of Lompoc, Santa Barbara County Fire Department, Vandenberg Air Force Base, county supervisors, U.S. Bureau of Reclamation (Bradbury Dam operator), and radio and television stations serving the area. Warnings are disseminated to the public by radio and television stations, sirens, public address systems on police and fire vehicles, and by telephone.

Original cost of the Santa Ynez River flood warning program was approximately $50,000 including acquisition and installation of equipment, development of the watershed model and associated staff time. Original costs were met largely by the Flood Control and Water Conservation District with contributions from the U.S. Air Force and other anticipated beneficiaries of the program. Annual costs for operation and maintenance of the program vary according to the amount of time the flood recognition system is in use but are estimated to be about $1,000 excluding staff time. Estimated staff time devoted to the operation and maintenance of the system is estimated to range from 1/3 to 1/2 man-year annually. Major beneficiaries of warnings assist in meeting operation and maintenance costs.

Views of Local Officials

Santa Barbara County Flood Control and Water Conservation District. The principal results of the system are: a) increasing the advance warning of floods from 2 hours which was available without the system up to about 8 hours at Bradbury Dam and 12 hours at Lompoc; and b) availability of information on the severity of impending floods. In addition, development of the system and the data collected through the system have added considerably to knowledge of watershed's hydrology. Benefits of the early warnings which are issued include:

1. Safety through provision of adequate time for evacuation of persons living in areas subject to flooding;

2. Reduction of damages through enabling evacuation of movable property and an early beginning of flood fighting activities;

3. Earlier post-flood recovery and lesser rehabilitation cost; and

4. Improvement of reservoir regulation, providing both reduction of flood damages and water conservation benefits.

The system is considered to be highly reliable. The only significant operational problem experienced to date has been transmission of an occasional false reading from a gage due to a lightning strike in the vicinity. However, false readings are indentifiable and therefore cause no false predictions of flood levels. System accuracy has proved excellent. Figure A-7 shows predicted versus actual hydrographs for a flood occurring March 3-5, 1978. Forecasts have a high credibility with the public.

No adverse public reaction to the system has been experienced. Local elected officials support the system and have raised no objections to provision of funds for operation and maintenance. No problems with liabilities or legal action of any type have arisen from operation of the system and none are anticipated. The principal concern associated with use of the system is maintenance of the technical capability on staff which is necessary for its continued operation.

The overall assessment of benefits of the warning system is that the investment is returned a thousandfold.

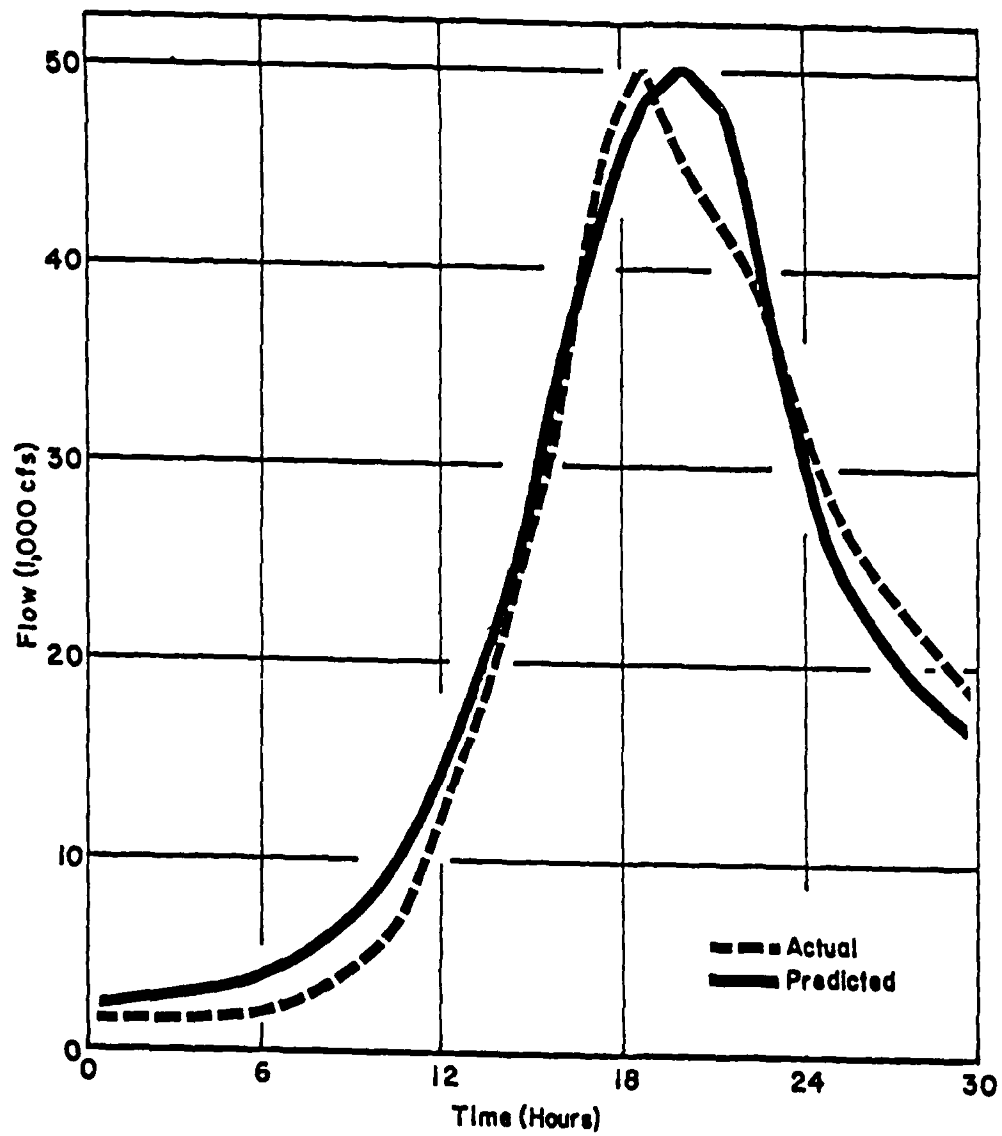

FIGURE A-7. PREDICTED VS. ACTUAL INFLOW TO LAKE CACHUMA

Santa Barbara Sheriff's Department. Advance warnings of floods received from the Santa Barbara County Flood Control and Water Conservation Department are relayed by the Sheriff's Department to the County Administrator. Warnings are also used by the Sheriff's Department for preplanning of emergency activities and for scheduling and placement of personnel. The system is considered to be dependable and acted on without further confirmation. The principal benefit of the system in the view of the Sheriff's Department is the increased safety of flood plain residents.

U.S. Bureau of Reclamation (Bradbury Dam Operations). Predictions of flow into Lake Cachuma and other information available from the Santa Ynez River flood warning system are used in operation of Bradbury Dam in a variety of ways including:

1. Warning of persons immediately downstream of the dam about impending releases which could cause flooding of lowlands so that livestock, equipment and other property can be moved to safety or otherwise protected;

2. Determining the need to hire staff necessary to operate the dam during periods when releases are being made and scheduling work hours;

3. Avoiding over-release of waters which would waste valuable water and increase downstream flooding;

4. Coordinating the operation of the several dams on the river; and

5. Scheduling minor manipulations of dam outflows to avoid coincidence of outflows from the dam with peak flows otherwise occurring on the river.

The warning system is believed by the Bureau's representative to be reliable and fairly accurate and creditable with the public. The availability of the advance warning is thought to be of considerable value to the Bureau's operation although the amount of benefit cannot be easily determined. With respect to the overall Santa Ynez Valley, the warning system is viewed as being very effective in terms of providing safety and tremendously productive as a means of reduc - ingflood damages.

Vandenberg Air Force Base. Officials at Vandenberg Air Force Base place sufficient value on warnings provided by the flood warning system that they have had installed and pay for a private line to the offices of the Santa Barbara Flood Control and Water Conservation District to assure immediate availability of warnings. Warnings received are deemed to have sufficient credibility and accuracy to serve as an immedate basis of action. The value of warnings to the base is in benefits which result from:

1. Provision of time necessary to reroute electrical power and communications to secure continuity of operations to various activities including those relevant to national security and avoidance of expensive "holds" in spacecraft launchings;

2. Relocation of contents from and protection by sand bagging of administrative offices, spacecraft assembly buildings, base shops, and vehicles;

3. Initiation of patrols for erosion and bridge damage and protection of various utilities crossing the Santa Ynez River, leading to faster recovery from flood damage.

4. Increased safety of base personnel; and

5. Improved overall handling of flood situations by providing the time necessary for a systematic and well-planned response.

As noted earlier, damages at Vandenberg Air Force Base due to the January 1969 flood were approximately $3 million. Officials estimate that the availability of early warnings would cut losses by at least one-half in any future recurrence of a flood of that magnitude.

City of Lompoc. Up to 10 hours advance notice of floods are provided to the City of Lompoc by the Santa Ynez River flood warning system. Use is made of the warning by the city to:

1. Notify city police, community development, fire, and utility departments to make appropriate increases in on-duty staff or place crews on stand-by to prepare for warning evacuation, debris clearance, sandbagging and other flood-related activities;

2. Valve off water and sewage lines crossing under the Santa Ynez River to avoid contamination of potable water supplies and spills of raw sewage;

3. Begin patrols of the river bank, evacuate a city park and campground vulnerable to flooding, begin observation of streets leading to flood-prone areas and take other actions to assure safety;

4. Prepare and test the city's auxiliary electrical power system;

5. Prepare sandbags and sand for use, provide sandbags and sand to residents and begin sandbagging to protected selected areas;

6. Warn city residents; and

7. Warn outlying commercial and industrial establishments and farmers.

The warning system is thought by Lompoc city officials to be very reliable. No difficulties whatsoever of a legal or other nature have arisen in connection with the distribution of warnings.

WISE COUNTY, VIRGINIA

Wise County is located in the southwest portion of Virginia. The principal streams with headwaters in the county are the Powell and Guest Rivers, each of which have numerous tributaries (Figure A-8). The Clinch River, with headwaters approximately 60 miles upstream, flows through the southeast portion of the county.

The Powell River watershed forms a rough circle approximately 14 miles in diameter. The city of Appalachia (1970 population of 2,161) is located at the

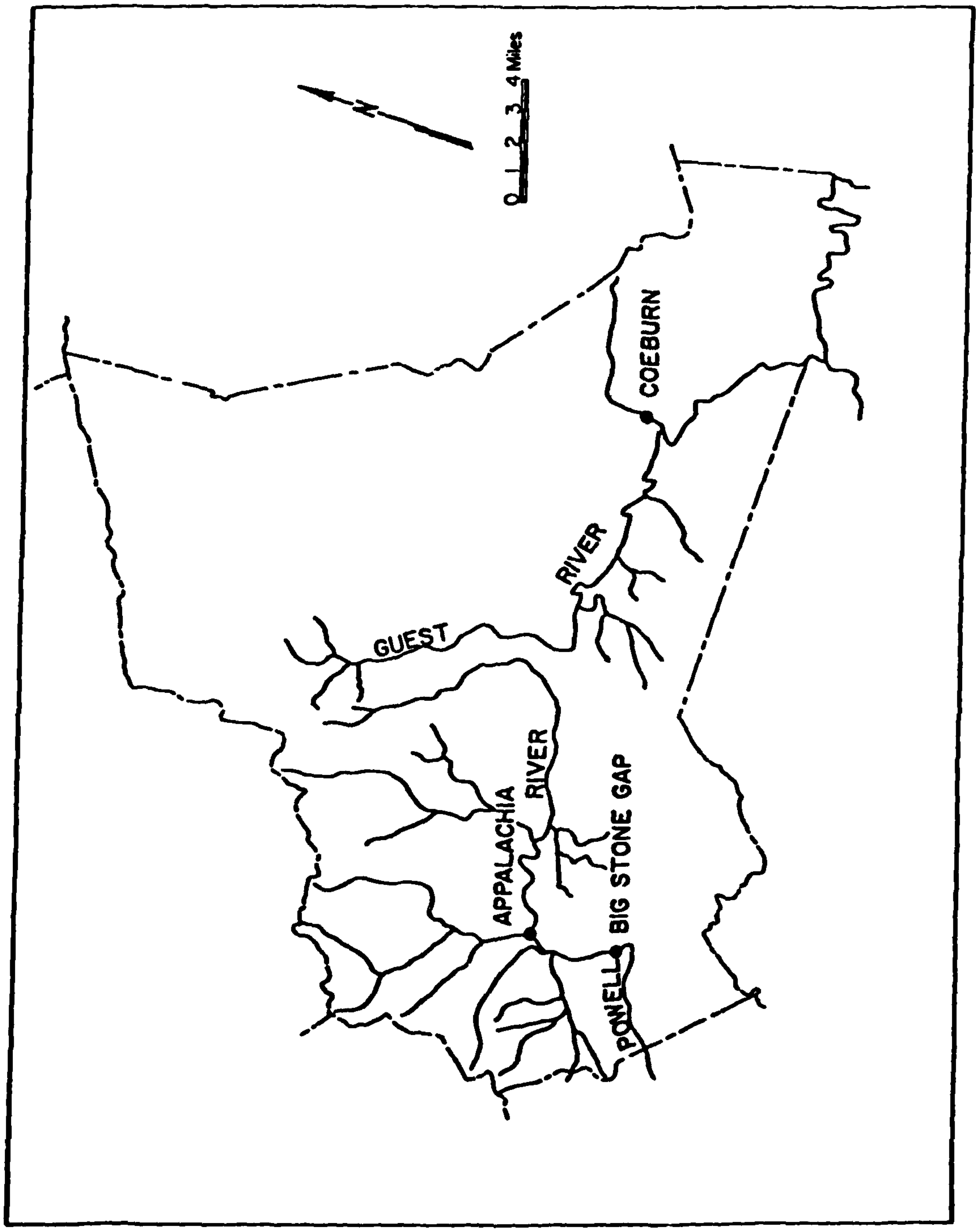

FIGURE A-8. WISE COUNTY, VIRGINIA

junction of the Powell River and Callahan Creek, one of its major tributaries. Callahan Creek has a drainage area of 28.9 square miles and at the lower end of the city, the Powell River has a drainage area of 108 square miles. There is residential development on both sides of the Powell River, with considerable commercial and residential developments on the flood plains of both the Powell River and Callahan Creek.

Big Stone Gap (1970 population of 4,153), is about three miles downstream of Appalachia, at the junction of the Powell and South Fork Powell Rivers. The drainage areas of the Powell and South Fork Powell Rivers at Big Stone Gap are respectively 157 and 40.9 square miles. Most of the business and residential developments at Big Stone Gap are on high ground between the two rivers and on the north side of the Powell River but there are important commercial and residential developments on flood plains along both rivers.

The city of Coeburn (1970 population of 2,362) is located in the Guest River watershed at the junction of the Guest River, Toms Creek and Little Toms Creek. The downtown portion of the community and some residential developments are located on the flood plains of the several streams.

Topography in the vicinity of all of the communities is hilly. The upper portion of both the Powell and Guest River watersheds are mountainous. Streams in the upper areas are characterized by V-shaped valleys and very steep gradients. Lower reaches of the watershed are less steep but still produce high water velocities.

Extremely intense rains can occur in the area. In Nelson County, located a short distance northeast, rainfall amounts of 22 inches within 24 hours have been recorded. Most heavy rains occur in the period of December through March. However, flood-producing rains can occur in any month.

Floods occur frequently along the rivers and streams in Wise County. In major floods, the water level can raise as much as 14-18 feet at rates of rise of 5-6 feet per hour for small streams and the Guest River at St. Paul can rise 25-30 feet at rates of rise of 3-4 feet per hour. More than 30 floods have been noted in the Powell River drainage since records have been maintained and more than 10 along the Guest River. Severe flooding occurred most recently in April of 1977 when 7 inches of rain in 22 hours caused water levels exceeding the projected 100-year level on most streams in the county.

Flood Warning System

The impetus for establishment of the Wise County flood warning program was the flooding experience in nearby Nelson County which had received 22 inches of rain in 24 hours when Hurricane Camille struck in 1969. Recognizing that Wise County was similarly vulnerable to severe flooding and that early warnings would be beneficial, the Wise County Director of Civil Defense began development of the existing system. Figure A-9 shows a schematic illustration of the existing system. The first precipitation gage, costing $3.00, was purchased in 1971. Simultaneously, LENOWISCO, a regional planning commission for Lee, Wise, and Scott Counties organized a joint effort with the three counties, the Tennessee Valley Authority, and the National Weather Service to perform hydrologic studies and develop flood prediction charts.

Flood recognition system equipment now in place in Wise County includes 15 plastic rain gages and 8 observer-read, river-level gages. Rain gages are located at the Wise County Emergency Operating Center, at homes of civil defense staff members, officials of the several communities served by the system, and with other volunteers scattered throughout the county. Most of the gages are equipped to be read remotely so observers can take readings without leaving their homes. River-level gages are either painted on bridge abutments or consist of metal tapes mounted on wood posts. In addition, there are two stream-level recording gages on county streams which can be accessed by telephone. These gages were installed and are maintained by the Corps of Engineers.

Weather information provided by the National Weather Service is received at the civil defense office over the Virginia State Police teletype, NAWAS telephone circuit and NOAA weather radio. The flood recognition system is activated by the Civil Defense

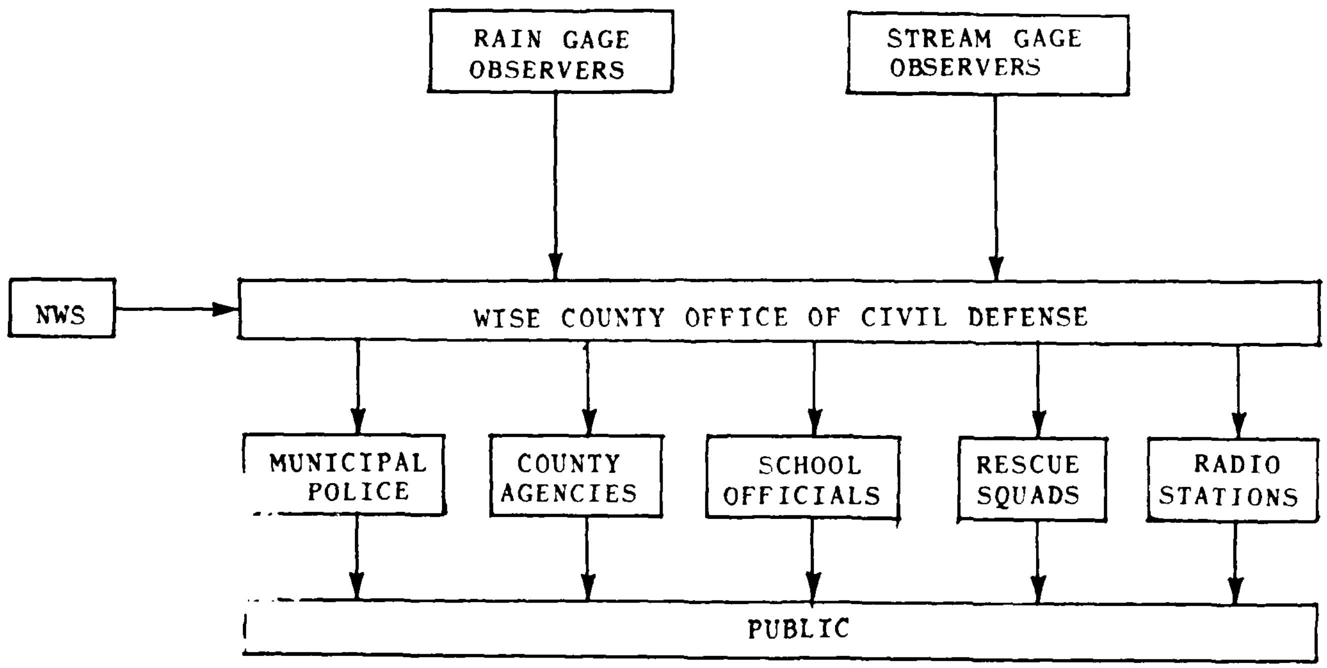

FIGURE A-9
SCHEMATIC ILLUSTRATION
OF
WISE COUNTY, VIRGINIA
FLOOD WARNING SYSTEM

Director, Civil Defense Coordinator, or other senior staff member when information such as a NWS announcement of a flash flood watch indicates heavy rains are anticipated. The system can also be activated by any of the observers who note rainfall in excess of 2 inches in 24 hours at their location. Communications with observers are by telephone, backed up by police radio for key observers. As needed, police furnish mobile radio contact at all observer locations.

Information on rainfall received from observers is used to forecast flood stages. Forecasts are issued to police dispatchers, rescue squads and community officials in the area concerned, to county agencies and officials, to school system officials, and to radio stations serving the area.

Information relating predicted flood heights to areas inundated has been assembled for most flood-prone portions of the county. Individual communities disseminate warnings to persons in affected areas by sirens and public address systems on police and rescue vehicles and by knocking on doors. Reports from river level gage observers are used to confirm early predictions of flood stages.

The cost of installing the river-level gages for the system was approximately $25 each, including labor. The rain gages which are now used cost approximately $15 each. It is estimated by the Wise County Civil Defense Director that a system like that in place could be installed by two persons in one week for less than $1,000. Maintenance cost to the county for the system is about $100 annually, mainly for replacement of river level gages which are washed out. About 40 man-hours per year are required to inspect and maintain the system.

Views of Local Officials

Wise County Civil Defense Office. The area has historically been subject to a large number of floods. Before the system was installed, there was always a lack of information on which to base decisions. The result was the frequent issuance of warnings to the public, a large number of which were false alarms and which consequently hurt the credibility of succeeding warnings. The lack of information also resulted in unnecessary activation of the National Guard a number of times and unneeded action by residents in the area. With the system, predictions within half a foot of the final crest stage can be made 4-5 hours ahead for a 4-foot rise in stream levels. Predictions of a 24-foot rise made in April 1977 were within 2 feet of the measured crest height even though they were made 14 hours in advance of the flooding.

The system was activated about 70 times between 1971 and 1979. Floods actually occurred in five of those cases and the predictions that were made proved accurate in each instance. Persons who didn't react to warnings the first time or two have had the opportunity to see the accuracy of the predictions and now 80 to 90 percent of the people voluntarily evacuate when warned to do so.

Numerous benefits come from the system including:

1. Avoidance of costs associated with false alarms;

2. Safety of area residents through warning, evacuation, blocking of dangerous roads, and readiness of rescue crews and civil defense personnel;

3. Safety through better information on when to transport children from school to home in order to avoid flood dangers. Children were formerly released whenever a problem occurred;

4. Floodproofing and evacuation of contents by property owners and movement of mobile homes; and

5. Utility system management to reduce losses to water and sewer systems.

Every house on the flood plain benefits to some extent through reducing damages and, altogether, the savings are tremendous. As an example, saving of 350 automobiles by their timely movement to higher ground was attributed to early warnings in flooding which occurred in 1977. At least $25,000 in negative costs were saved on one weekend by not overreacting to a potential flooding situation. The gross productivity of the county is greatly increased by this type of saving. The value of warnings can't be measured just in dollars. The system does a lot of good and is just an excellent investment of time and labor.

Both the general public and local officials support the flood warning system. Auto parking areas from which river-level gages can be read are sometimes so crowded that official observers have to wait their turn to see the gages. Following the April 1977 flood, the County Board of Supervisors passed a resolution of commendation for operation of the system and newspapers in the area have run editorials recommending people take warnings seriously. Both public officials and other parties call in frequently for information.

City Administration of Coeburn, Virginia. People in Coeburn thought the city would never flood again after completion several years ago of a small flood control channel through the center of town. In April of 1977 the city did flood--almost to the tops of the parking meters.

Warnings about the flooding were received from civil defense about 8 o'clock in the morning. By 9 o'clock, police, fire and rescue squad personnel were put on standby, a command post was set up and the city council was alerted. By noon, city equipment had been moved out of the floodplain and merchants and the public had been notified by telephone and bullhorn. Everyone had about 10 hours to prepare for the flooding which began late that night.

As a result, there were millions of dollars of savings. At least $150,000 of fire equipment and thousands of dollars of communications equipment, vehicles, graders, backhoes and other city equipment was saved. By shutting down and protecting pumps on our water and sewer system, several thousand more dollars were saved as well as maintaining the capability to restore service immediately after the flood. The pumps and motors would have been ruined if they had been left on. Replacement equipment would have cost at least $20,000 and taken six months to obtain, during which time the city would have been without sewer service.

The advance warnings of flood also gave time to open schools for evacuees and set up emergency routes. Several lives can definitely be attributed to the emergency communications that were set up. Several lives would have definitely been lost if there had been no warnings. Warnings also provided the time necessary to set up security arrangements to prevent looting and vandalism in evacuated areas.

The warning system also lets the city avoid unnecessary activation and overtime which are very costly. Experience with the warning system has shown it to be so reliable and accurate that it can be depended on totally.

City Administration of Appalachia, Virginia. Warnings of the April 1977 flood were received by telephone and radio at the police department and city manager's office. First, alerts were received when the storm started moving in. Then 3-4 hours of warning was given that a flood would definitely occur. That was enough time to warn people and evacuate the flood plain areas and, consequently, not a single life was lost. The city also was able to save mobile equipment, shut valves on the water and sewer system and shut off electrical power to some motors. For a flood like the one in 1977, the warning system saves $200,000-$300,000 of public property losses.

With the time available, police were able to set up traffic control arrangements and aid motorists. The fire department was able to disperse its equipment. Warnings were given to the public by fire and rescue squads using public address systems and by knocking on doors. People saved a lot of their property by stacking it, moving it to upper stories or evacuating it to another place. There's just no way to calculate the return from the warning system. Plus the saving of lives, hundreds of thousands of dollars can be saved for a few pennies.

Warnings have a very good credibility with the public. There was a very good response to the evacuation request. The accuracy of the system couldn't be much better. Several times the predictions have been almost exact and other times they have been only inches from what actually happened. There is no concern at all about reliability either. The city is definitely prepared to act immediately on the basis of warnings.

Police Department of Big Stone Gap, Virginia. The 4-6 hours warning of the April 1977 flood were used to evacuate areas that would be isolated by flooding, take care of the elderly, ill and others needing special help to evacuate, assemble rescue forces, and to spread out police and fire equipment. As a result, there was no life lost even though the flood was a disasterous one. People were also able to save a large amount of personal property by stacking it or moving it. The warnings let them know how much time they had and how high the flood would be.

The accuracy of the system has been just about exact and there are no concerns whatsoever about the reliability of its operation. And accurate and reliable warnings are essential. Volunteers can only be called up so many times on false alarms and only so many unnecessary warnings can be given before people develop a false sense of security.

The city council realizes the benefits of the flood warning system. They are now pushing for similar systems for other types of disasters.

SWATARA CREEK FLOOD WARNING SYSTEM

Swatara Creek originates in Schuylkill County, Pennsylvania, about 40 miles northeast of Harrisburg. From there, the creek flows in a southeasterly course through Lebanon and Dauphin Counties and empties into the Susquehanna River at Middletown, Pennsylvania (Figure A-10). The creek is approximately 65 miles long and has a drainage area of 576 square miles. Numerous tributaries enter the creek along its length.

The upper reaches of the watershed in Schuylkill County range from forested hills to very steep uplands, much of which is extensively mined for coal. The lower portions of the watershed in Lebanon and Dauphin Counties are characterized topographically by rolling hills which contain extensive areas of cropland. The overall population of the watershed in 1970 was about 156,000 with roughly half living in the larger municipalities within Dauphin and Lebanon Counties and the remainder distributed in smaller communities throughout the watershed and in rural areas.

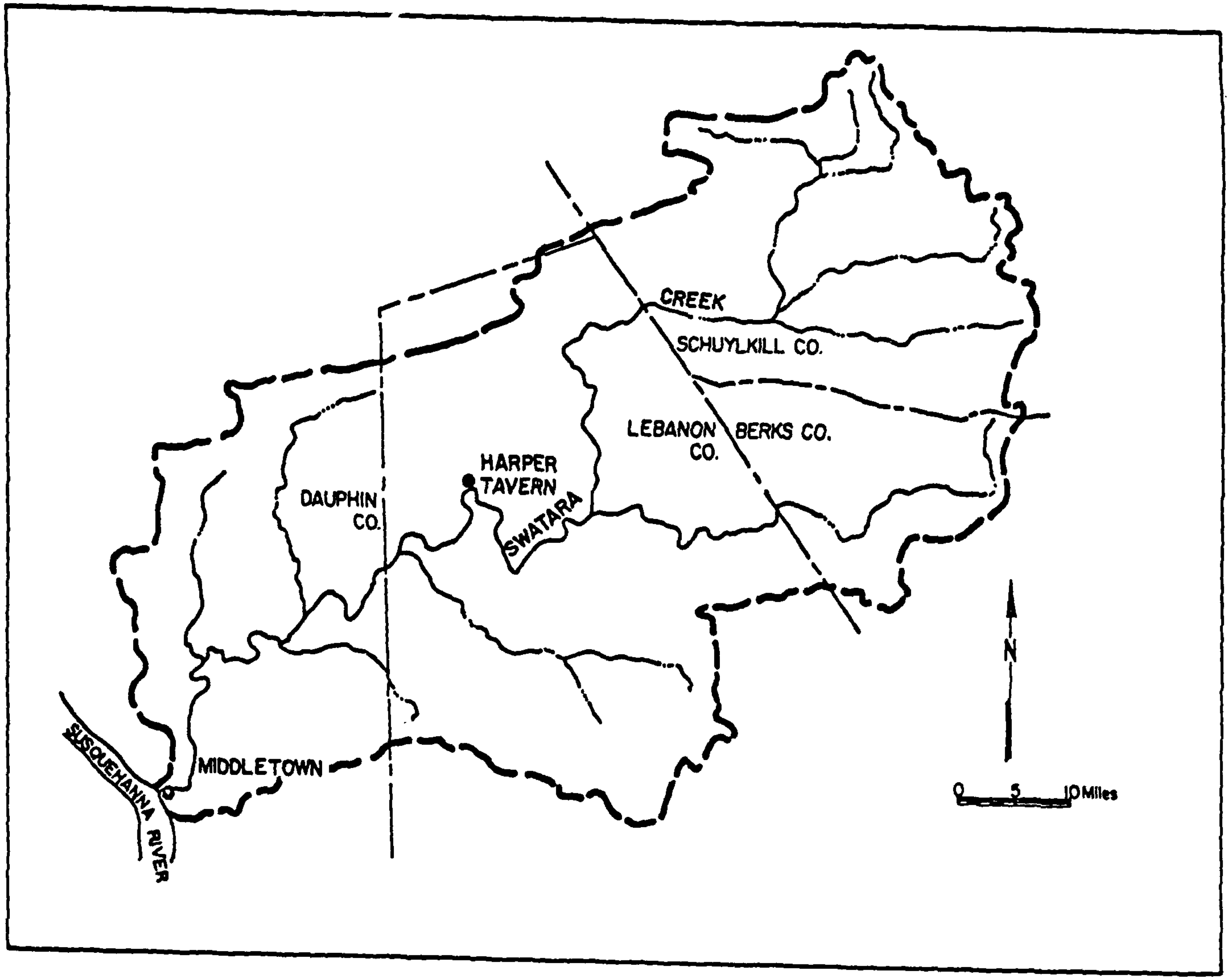

FIGURE A-10. SWATARA CREEK WATERSHED, PENNSYLVANIA

Average annual precipitation in Swatara Creek watershed ranges from 40-45 inches. Most of the precipitation occurs from May through August with an average of 30-35 thunderstorms yearly accounting for most of the summer rain. Tropical hurricanes rarely reach the area with destructive winds but can cause intense rainfall. Average snowfall is about 35 inches per year and snow melt is a significant component of late winter and spring floods.

Swatara Creek floods frequently with some 129 instances of out-of-bank flows being recorded between 1919 and 1960 at Harpers Tavern, Pennsylvania. Severe floods occurred in 1889, 1933, 1972 (Hurricane Agnes) and 1975 (Hurricane Eloise). The June 1972 flood caused greater property damage than any previous flood with approximately 1,100 residences and 150 commercial and industrial structures being damaged or destroyed. There was also severe damage from the flood to agricultural lands and properties and to roads. Areas of concentrated developments subject to flooding lie in Londonderry Township and near Middletown.

Flood Warning System

The Susquehanna River Basin Commission held a conference shortly after the widespread flooding caused by Hurricane Eloise in 1975 for the purpose of identifying problems which had been encountered and needed actions. Lack of warning was identified as a serious problem which contributed to losses throughout the area and Swatara Creek watershed was ranked as the part of the area where improvement of flood warning arrangements was most urgently needed. The Commission subsequently undertook to stimulate development of a flood warning system for Swatara Creek through development of a plan for the proposed system and hosting of meetings with various officials from the three affected counties. Agreement was reached among the three counties to operate the flood warning system and, six months later, the system became operational. Figure A-11 illustrates the operation of the system.

The concept of operation of the Swatara Creek flood warning system is:

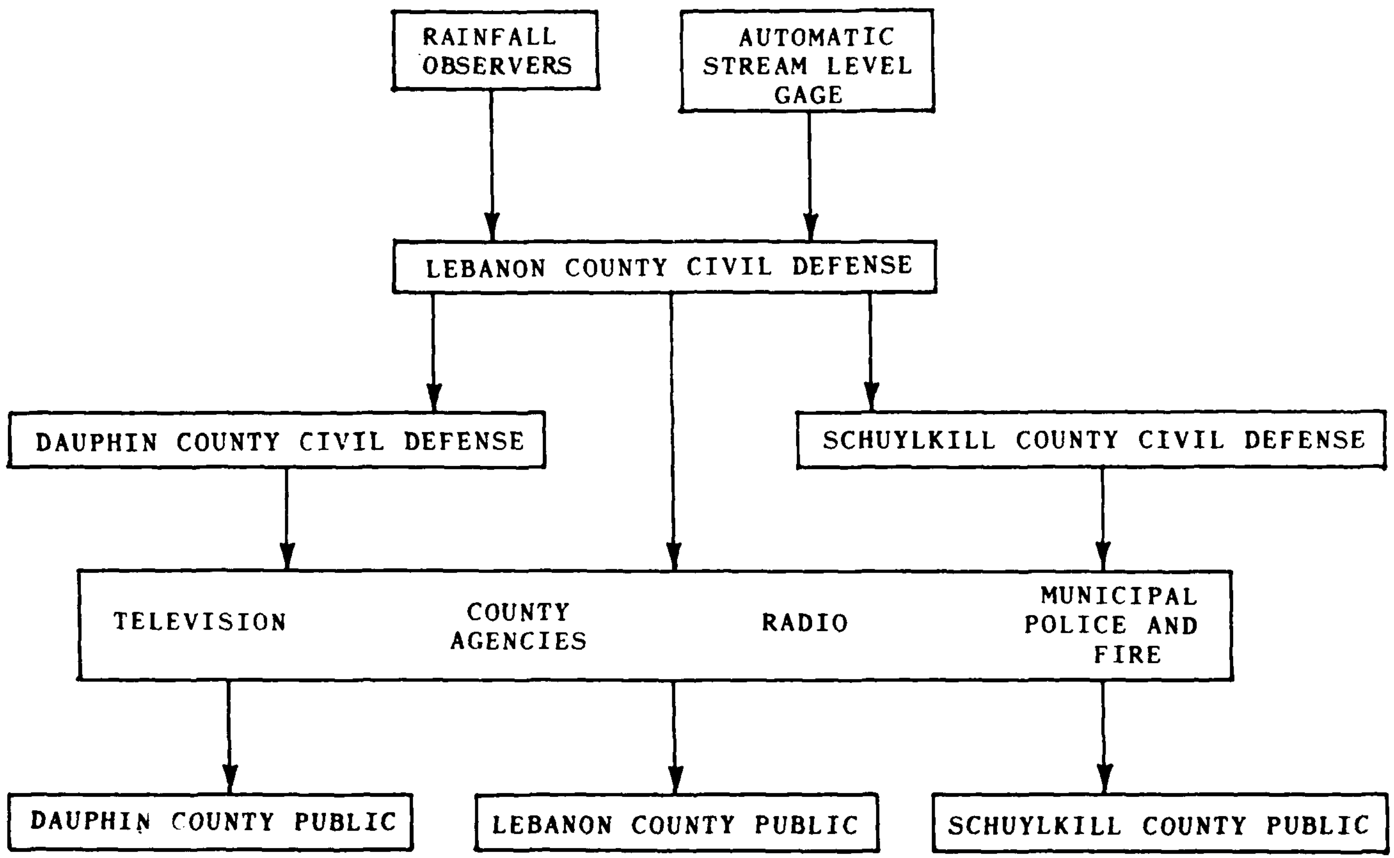

FIGURE A-11
SCHEMATIC ILLUSTRATION
OF
SWATARA CREEK, PENNSYLVANIA
FLOOD WARNING SYSTEM

1. Use of information provided by six volunteer rainfall observers to predict flood stages at Harpers Tavern, Pennsylvania;

2. Use of crest-stage relationships between Harpers Tavern and downstream locations to predict crest stage and time of flooding for other vulnerable places;

3. Use of an automatic stream stage recorder at Harpers Tavern to confirm flood forecasts; and

4. Distribution of warnings from county Civil Defense agencies to various municipalities and, through them, to the public.

Technical aspects of the flood recognition system were developed by the National Weather Service. The Susquehanna River Basin Commission provided precipitation gages and installed 10 river-level gages at various stream crossings to provide information for calibration of the system. Original cost for purchase and installation of the several river-level gages was $15,000, including labor, paid for by the Susquehanna River Basin Commission. Annual operating and maintenance costs for the river-level gages of about $1,500 are shared by the Pennsylvania Department of Environmental Resources and the U.S. Geological Survey.

Coordination of the flood recognition system and preparation of flood forecasts are provided by the Lebanon County Civil Defense Director. Rainfall observers are alerted to begin rainfall measurements whenever information received from the National Weather Service by teletype or radio indicates heavy rains are expected. The observer network is also activated upon request of the Civil Defense Director of any of the three participating counties in the event locally heavy rains occur. Rainfall observers also have a standard operating procedure for self-activation of the system if more than 1 inch of rainfall is received in any 24-hour period.

After their preparation, flood forecasts are distributed by radio from the Lebanon County Civil

Defense Director to the civil defense directors of Dauphin and Schuylkill Counties. All civil defense directors then issue appropriate warnings to local fire, police and other emergency services agencies and to radio and television stations. Warnings to the general public are provided by radio and television and by police and fire vehicles with public address systems. The warning system provides a general warning time of about 10 hours in the central portion of the watershed and about 15 hours at Middletown. Confirmation of flood flows through observation of staff gages enables about 1 hour of highly accurate warning of flooding.

The system has been used three times since becoming operational in 1976. Other than when it is active, no county staff time is devoted to the system.

Views of Local Officials

Dauphin County Department of Emergency Services. Prior to development of the Swatara Creek flood warning system, knowledge that flooding was going to occur in Dauphin County was based on reports of flooding in immediately upstream areas. This approach gave about 1-hour advance notice. Even then, deciding how severe the flood would be and what areas should be evacuated was only guesswork. The biggest benefit of the system is the definite forecast of the flood height and the time when the crest will arrive.

While a repeat of the 1972 flood would probably cause several deaths without the warning system, the only deaths now anticipated in a severe flood are those persons who ignore warnings or make foolish mistakes like trying to canoe on the flood waters.

Damages from floods are also reduced. The 1972 flood caused an almost 100 percent loss of contents of residences in Londonderry Township. With the approximately 15 hours of warning available, it is estimated that the loss of contents can be reduced about 90 percent. Costs for pickup of discarded items are reduced as well as the time required to return to normal operations. In addition, the warning system eliminates overreaction on the part of both private parties and public bodies and therefore saves these costs.

The three counties participate in operation of the system by mutual consent and without any formal agreement. No problems have arisen in the arrangement. Local officials in the area are aware of the system, support it and depend on its operation.

The system is considered to be very reliable because telephone communications between counties are backed up by radio, mobile radio units can be dispatched to back up telephone communications with rainfall observers, and all personnel responsible for making flood forecasts and issuing warnings are backed up by alternates. Accuracy of the system has been excellent with estimates of the time of arrival of flood crests being "on the button" and estimates of crest height have been within half a foot of what actually occurred. The opportunity for the public to view the accuracy of the flood forecasts in past floods has made "real believers" of them.

No problems have occurred in operation of the system. The only concern of any importance is the possibility of an unneeded evacuation of mobile homes in one area on the basis of what turns out to be a "near miss." However, residents there are less likely to be falsely evacuated now than they were before the warning system was developed. In any event, the concern about potential liability has not been great enough to prompt any specific action to guard against it.

Susquehanna River Basin Commission. The Swatara Creek flood warning system works in the absence of any formal agreements because the three counties are bound together with a common problem. There are presently about 25 flood warning systems operational in the portion of Pennsylvania within the area covered by the Susquehanna River Basin Commission. There have been no problems with the operation of any of the systems.

During Agnes, trailers were washed away. With warning, trailers can be moved in a matter of a few hours. Warning also enables getting large equipment to move large LP-gas tanks. Without warning in Agnes, a restaurant was flooded to the roof level causing a loss of all contents. With warning, evacuation of only the partial contents of a walk-in freezer saved food valued at $25,000.

A water pumping plant lost all of its equipment during Agnes and was shut down for several days. During a recent storm, the pumping plant was able to lift its large electric motors and electric breaker panels above flood levels. The estimated cost savings was $7,000-$8,000. However, more importantly, the plant manager reported that the flood warning system allowed them to shut down for far less time than during Agnes, and that they could put the plant back into operation faster because they also knew when lower water levels were coming down the stream.

There are many examples where homeowners were evacuated by boat during Agnes. In the recent storm, people were evacuated earlier with far less danger, and many homeowners were able to move appliances, furniture and other items to higher levels out of harm's way. Early warnings and accurate water level predictions also permit timing of evacuations when it is safer for the rescuer. In Agnes, some rescues were made at night with a rowboat when water was up to the treetops.

The warning system is viewed as providing the kicker to get civil defense going at the county level. It also provides a way that local governments can participate in efforts to reduce flood losses.Everyone benefits from a better understanding of events and the capability to make planned responses to floods. In terms of reducing flood losses, there can be a significant reduction of damages to contents based on warnings. This provides a big return for hardly any cost which is especially helpful for areas for which there is no structural solution.

LYCOMING COUNTY, PENNSYLVANIA

Lycoming County is located in the north central portion of Pennsylvania, about 90 miles north of Harrisburg. The county has an area of 1,215 square miles. The majority of the lands in the county are heavily forested and remain undeveloped due to their steep slopes. Flatter areas in the river valleys and the milder slopes are used primarily for agriculture. The majority of the county's population and commercial development is located on the valley flood plains in close proximity to the major streams and their tributaries.

Agriculture in the county is gradually decreasing, due at least in part to expansion of urban areas and increasing demand for recreational lands. As agriculture declines, commercial and industrial activities are becoming a more important part of the overall economics base of the area. One of the larger employers in the county is the Sprout Waldron Company, a manufacturer of various types of industrial machinery. The county's population was 115,123 as of 1977. It is expected to increase to 122,600 by 2000.

Physiographically, the county lies at the junction of the Applachian Plateau Province and the Valley and Ridge Province. The Allegheny Front, which separates the two provinces, is an escarpment trending east-west across the county. The topography of the county is varied with broad flat ridges across the highest elevations, several broad valley areas at intermediate elevations and several major stream valleys disecting the area north to south. Slopes in the area are relatively steep and stream gradients range from as much as 10 percent in the uplands to about 5 percent in the lower valleys.

Lycoming County lies entirely within the Susquehanna River Basin. The West Branch of the Susquehanna River flows through the county for a distance of about thirty-eight miles. Its major tributaries in the area are Pine Creek, Little Pine Creek, Larrys Creek, Lycoming Creek, Loyalsock Creek, and Muncy Creek (Figure A-12). There are also numerous smaller tributaries. Altogether, the county has approximately 2,200 miles of streams.

The mean annual precipitation in Lycoming County is 40 inches. Precipitation is relatively well distributed through the year with May and July being the wettest months. Intensive rain occurs in the area as storms or tropical disturbances move north and east from the deep south. Hurricanes occasionally affect the area, the most recent occurrences were Hurricane Agnes in 1972 and Hurricane Eloise in 1975. The hurricane season lasts from June to November. These storms cause as much as 4-8 inches of rain in 24 to 48 hours in the county.

Floods occur frequently along Lycoming County streams. For example, Lycoming Creek exceeded its bankful stage 44 times in the period 1914-1958. Recent

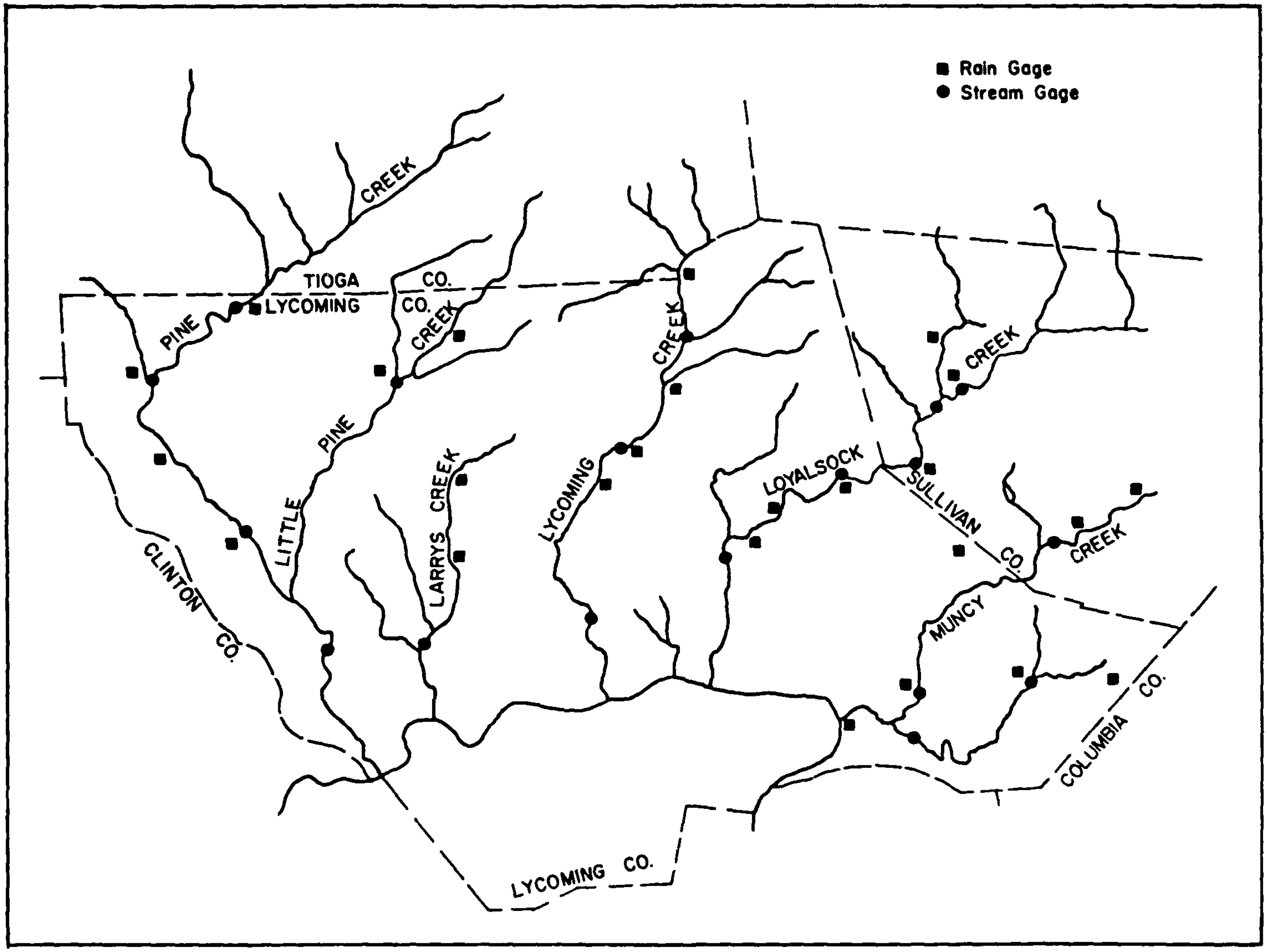

FIGURE A-12. LYCOMING COUNTY, PA.

major flooding in the county occurred in 1950, 1959, 1964, 1972 and 1975. Flooding causes damages to roads, bridges and other public property as well as to crops, residences, commercial and industrial structures, and contents of structures.

The worst general flooding of recent record in the area occurred due to rains from Hurricane Agnes in 1972 and Hurricane Eloise in 1975. During the 1972 flooding, thousands of buildings were destroyed or damaged and many millions of dollars of damage was done to industrial, commercial and agricultural properties and activities. Severe flooding, rivaling that which followed Hurricane Eloise in severity, also occurred in March of 1979 in some of the county's watersheds.

Flood Warning System

County municipal officials experienced considerable difficulty in the severe flooding of 1972 in obtaining an accurate determination of stream levels and information as to whether stream levels were rising or falling. This difficulty resulted from the availability of only a single remote reading gage on the West Branch Susquehanna River and the malfunction of that gage during high water levels. Following the flood, the Lycoming County Board of Commissioners requested that improvements be made in arrangements for obtaining flood-related information. As a result, several staff gages for direct observation were installed along area streams. Further flood experiences resulted in supplementation of that system to also provide rainfall measurements and to add predictive capability. The existing flood warning system was developed by the Lycoming County Planning Commission, Lycoming County Emergency Management Agency, and National Weather Service. The countywide system incorporated and expanded on a warning system for Muncy Creek which was developed and operated by the Sprout Waldron Company for their own use.

The county's present flood recognition system consists of approximately 85 volunteers which serve either as observers or observer alternates. The observers and alternates are organized into separate data collection networks for Muncy, Pine, Little Pine, Larrys, Lycoming and Loyalsock Creeks. Each network of observers is supervised by a "stream coordinator." Figure A-12 shows the principal locations where information is collected on rainfall and stream levels. There are also numerous monitoring sites along Pine Creek in Tioga County which are not shown. Figure A-13 illustrates schematically the operation of the flood warning system.

Lycoming County's efforts to provide warnings of floods are supplemented by exchange of information with adjacent counties, all of which have flood warning systems based on observers. Communications with flood coordinators in adjacent counties is via radio.

The flood warning system is activated whenever an observer or network coordinator contacts the county Emergency Management Agency with information that a location has received a prescribed amount of rainfall (1 inch in winter or 2 inches in spring through fall). All observers are then contacted and requested to make hourly reports on rainfall and/or stream levels.

Precipitation data and stream levels are reported by observers to the stream coordinator. After consolidation of the data from observers in their area, stream coordinators report to the warning system coordinator. Based on the information received, the warning system coordinator releases flood predictions in close coordination with National Weather Service personnel and the Sprout Waldron Company.

Telephone is the primary means of communication with observers and stream coodinators. However, because of the vulnerability of telephone service to disruption, arrangements exist with amateur radio operators in the county to provide backup communications. The warning system coordinator, National Weather Service and other key parties are equipped with radio.

The warning system makes it possible to provide 6 to 8 hours advance notice of flooding to most portions of the county. Flood warnings generated through the system are issued to radio stations serving the area; city, county and state police; 34 fire companies serving the county; Pennsylvania Power and Light Company; Pennsylvania Department of Transportation; Pennsylvania Emergency Management Agency; and to

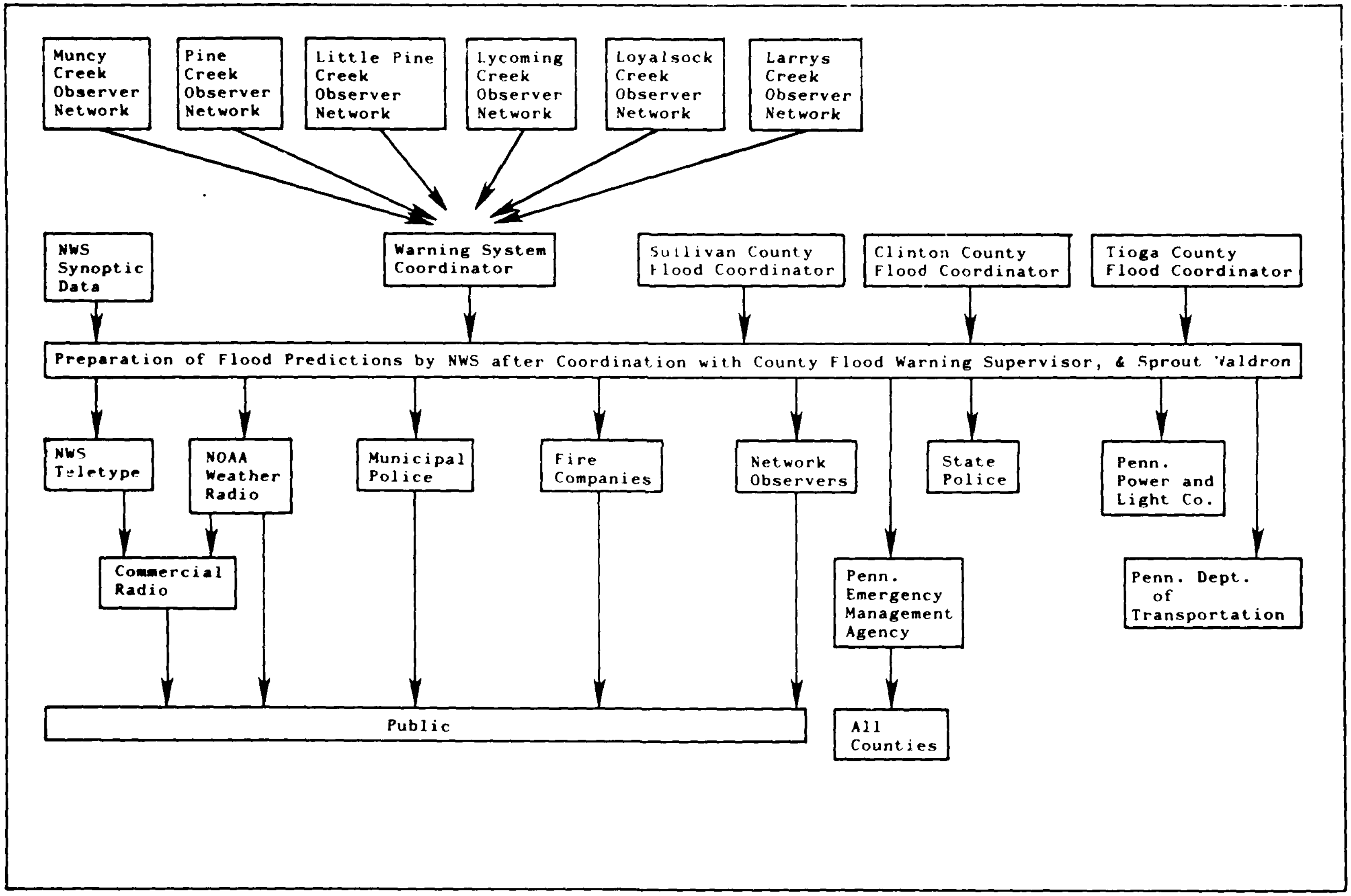

FIGURE A-13
SCHEMATIC ILLUSTRATION OF LYCOMING COUNTY, PENNSYLVANIA FLOOD WARNING SYSTEM

various businesses which have requested such notification. Warnings are also distributed over the NWS Weather Wire and NOAA Weather Radio. Stream coordinators and observers located in remote areas are also issued the flood predictions for dissemination in their vicinity. Local civil defense agencies and fire companies use fixed siren systems to alert populated areas to flood emergencies and both police and fire mobile public address systems are used to disseminate warning messages.

Formal flood preparedness arrangements in the county include standing contracts with schools and the Red Cross to provide for sheltering and feeding of evacuees. All local police organizations also have mutual aid pacts to provide sources of emergency assistance.

Precipitation gages and stream gages used by observers were furnished by the National Weather Service. Local industries, merchants, and governmental agencies donated necessary lumber, creosoting, technical assistance and labor to install the gages. As a result, local costs for equipment were only about $500. Continuing costs include an annual recognition dinner for observers, telephone charges for calls from observers and network coordinators, and professional staff time. About 25 man-days per year are devoted to operation of the system, not including time spent during periods of flooding.

Views of Local Officials

Lycoming County Planning Commission. The availability of accurate and timely flood warnings benefits a wide variety of people and interests. One major beneficiary is the County Board of Commissioners because it bears the responsibility for public safety. Liability due to lack of provisions for safety from floods was a serious concern prior to establishment of the warning system.

Industries also benefit significantly from the flood warning system. The opportunity to evacuate their equipment and other movable property before flooding reduces their losses greatly. It also enables them to

return much quicker to normal operations. This in turn minimizes economic dislocations and disruptions for the overall community. As an example, the Sprout Waldron Company's losses in the 1979 flooding were approximately $2,000,000, including physical losses of $429,000, emergency costs of $283,000, and business losses estimated to be $1,238,000. Their plant did not return to normal operations for almost six months. In contrast, the flood warnings available at the time of Hurricane Eloise in 1975 enabled protection of their property. Along with some permanent flood proofing that had been done, warnings enabled cutting the losses to about $8,000 in physical losses and $61,000 in emergency costs. In addition, the plant was 80 percent operational in about 3 days, holding business losses to an estimated $101,000. Overall, the losses were only $137,000 compared to the almost $2,000,000 experienced previously.

Residential property damages due to flooding are also greatly reduced by the availability of early warning. The flood in March of 1979 inundated about 580 homes. Yet the damage was so slight due to peoples' movement of their property after the warnings were given that it was not even necessary for the Federal Insurance Administration to send insurance adjustors to the area. Thousands of dollars have also been saved in other instances by avoiding unnecessary evacuations.

One of the most significant payoffs of the flood warning system is it's contribution to safety. It was necessary in prior flooding to use motorboats to rescue a number of people who had become trapped by unexpectedly high water levels. That posed a tremendous hazard for both the rescuers and those being assisted. The early warning system makes it possible to avoid those kinds of dangers by evacuating areas before they're flooded. The advance warnings also eliminate a great deal of chaos because the emergency agencies have the time necessary to prepare for action.

<u>Lycoming County Emergency Management Agency</u>. The flood warning system is seen as being of tremendous value to the Emergency Management Agency and the public. There is no doubt whatsoever that early warnings can save lives.

The system has been a real success in terms of both performance and payoff. The reliability and accuracy have been good and just one occasion to use the system in March of 1979 paid back it's cost a thousand times over.

Board of Supervisors, Old Lycoming Township. Flooding caught people by surprise in the cases of both Hurricane Agnes and Hurricane Eloise. The lack of warning was particularly serious in the case of Hurricane Agnes because of its severity. Many of the people who had to be evacuated were taken out by boat, some from the roofs of their homes. Other people were trapped in isolated areas for considerable periods of time. Up to a year was required to restore normality to the area.

The problems during the 1972 flooding almost became a real disaster. Levees protecting some areas were almost overtopped and it was only discovered at the last moment that the pumping stations for internal drainage were malfunctioning. These experiences with floods created a public demand for some kind of an early warning system.

The advantages of having a flood warning system were apparent in the flooding during March 1979. With approximately four hours of advance warning, police were able to make person-to-person contact with residents in low-lying areas to warn them to evacuate. There was also time to test the pumps which had previously caused problems, make preparations to feed and care for evacuees, and coordinate the activities of the Red Cross, Civil Defense and fire companies. In another flood like that which followed Hurricane Agnes, the warning system could result in a 40 percent reduction of losses in personal property. And what can be accomplished with a given length of warning time improves with experience.

The warning system is invaluable for the mental and physical well-being of residents. Before, the information on what was happening was confusing or wrong. Now, the information received is very accurate. As a result the people in the area have a great deal of confidence in the warning system.

<u>Lycoming County Board of Commissioners.</u> Local officials had the experience in 1972 with Hurricane Agnes of relying on a single mechanical gage to tell if the river level was rising or falling. Malfunction of the gage showed the need for having observers report on river levels and created some interest in a warning system. The flooding following Hurricane Eloise in 1975 showed the lack of arrangements for an organized and systematic appraisal of flood threats. Tremendous property damage occurred because of a lack of information.

These experiences triggered development of the present warning system. If these same floods occurred now, there would be a multi-million dollar savings of property damage and business losses. And minimizing industrial and commercial losses is very important. If industries begin closing due to large losses, one would follow another out of the area and the whole economic situation would unravel.

The flood warning system is also very important for reducing loss of life and losses to personal property. The Board supports it 100 percent.

Owen, H. James and M. Wendell

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